

EXHIBIT D

**Review of Material Analytical Services (MAS) Reports on Johnson & Johnson Talc Products
Identifying “Chrysotile” by Polarized Light Microscopy**

by

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Introduction

I graduated *cum laude* from Wellesley College with a degree in Geology in 1966. I received my Ph.D. from Columbia University in 1972 with a major in economic geology, and minors in mineralogy, petrology and mining engineering. I was appointed Assistant Professor by the Department of Agronomy at the University of Maryland in 1972, but one year later the appointment was transferred to the newly formed Department of Geology. I retired as Professor of Geology and Distinguished Scholar Teacher in 2014, but continue to hold an appointment as Professor Emerita. In addition to my academic appointments, between 2000 and 2014, I held a variety of senior level administrative appointments, including Assistant President and Chief of Staff, Vice President for Administrative Affairs, and Senior Vice President and Provost. Between 1979 and 2024, I published, among others, 47 articles on talc, amphibole and/or asbestos in highly regarded peer-reviewed publications. My work on mineral fiber and human health has been recently recognized by the United States Congress.

I taught polarized light microscopy and optical mineralogy at the University of Maryland, College Park for almost 30 years. My Ph.D. dissertation at Columbia University was in polarized light microscopy. I am thoroughly familiar with the methods of dispersion staining. My curriculum vitae is attached at the end of this report as Appendix 4.

I am being compensated at a rate of \$450 per hour for my expert work in this litigation. I have not testified at trial or deposition during the past four years.

I have reviewed numerous reports produced by MAS since 2020 involving the identification of “chrysotile” in Johnson & Johnson’s talcum powder products by polarized light microscopy involving dispersion staining techniques. A list of the MAS reports on this subject that I have reviewed is included as Appendix 5.

In my opinion, there is no scientifically-based evidence presented in these reports that supports the presence of chrysotile in any of the samples examined by MAS. Instead, the evidence presented is consistent with the conclusion that the particles MAS identified as chrysotile are actually composed of the mineral talc.¹

¹ One particle identified by PLM is neither talc nor chrysotile, but there is insufficient data available to specifically identify the particle beyond concluding that it is not asbestos.

In this report, I will discuss the raw data from the MAS reports to demonstrate my conclusion. I have selected examples that are typical, not unusual, to illustrate the points and I provide additional examples in the appendices. The types of raw data from particles identified as chrysotile from these reports that I specifically utilized for my assessment include:

1. Dispersion staining color parallel and perpendicular to the elongation direction of the particles,
2. Determination of the sign of elongation,
3. The relationships between particle size, retardation, and birefringence,
4. The extinction and interference patterns of the particles, and
5. The relief of particles in oil mounts.

I will also discuss the methodological issues of the MAS approaches, including impact of neglecting to correct for temperature variations, MAS deviations from standard methods of analysis, and other issues that impact the reliability of the MAS reports.

A. Polarized light microscopy: General considerations.

The polarized light microscope is highly specialized to enable examination of the optical properties of crystalline substances.

Figure 1 shows an overview of the polarized light microscope (Bloss, 1960²). The microscope differs from biological microscopes by the fact that there is a polarizer introduced in the system below the stage so that when the light enters the object, it is constrained to vibrate in only one direction, identified as North-South (N and S) in the figure. The object can then be rotated to look at light-object interactions in different crystallographic directions within the mineral. Because minerals are crystalline, the atomic structures of most are not the same in all directions, and their optical properties are also not the same in all directions; this is always the case for the two minerals with which we are concerned: talc and chrysotile. Imagine a pencil-shaped object on the microscope stage. By turning this object, you can observe how it affects light when its long side aligns with or crosses the light's vibration direction.

Another polarizer, named the analyzer, is placed in the optical path and is oriented at a 90-degree angle to the lower polarizer. There is also a slot for adding a "compensator," with MAS using one called Red I to determine the sign of elongation. Although not depicted in **Figure 1**, if a tungsten light source is utilized, a blue filter should be added above it. This filter reduces the red intensity from the tungsten, aligning the light spectrum more closely with that of the north sky, which appears as uniform, "white" light across the visible spectrum.

If a pencil-shaped mineral is positioned at an angle to the polarizer and analyzer, when light enters the mineral particle, a component of the light will travel through the mineral parallel to elongation and perpendicular, and when these two rays emerge, they will interfere. If the second polarizer is in the optical path, we will see interference colors like the colors one sees from an oil slick on water. If the angle is 45 degrees, we designate this the 45-degree position.

² Bloss, F. Donald, An introduction to the Methods of Optical Crystallography. Holt, Rinehart and Winston, New York, 1960. A list of references is included as Appendix 6.

Figure 1. Elements of the Polarizing Microscope (derived from Bloss, 1960³)

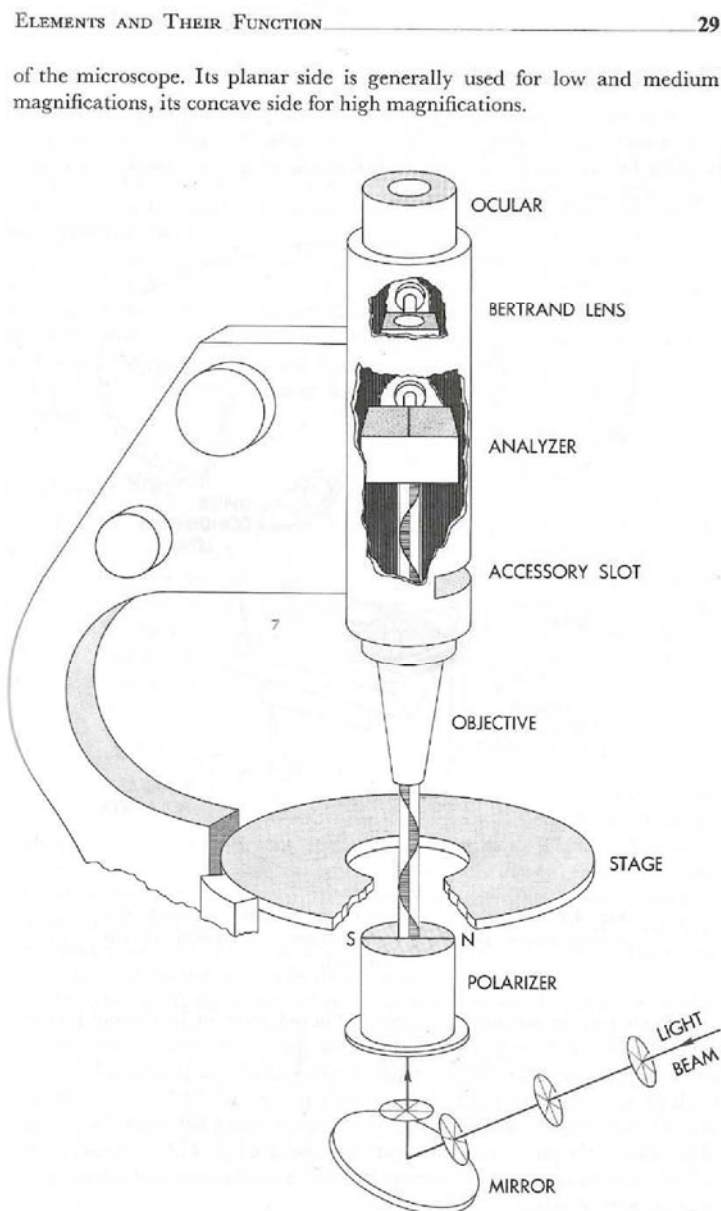


Fig. 4-1. Schematic diagram of the disposition of the more important parts of a polarizing microscope, mechanical details omitted.

³ Bloss, F. Donald, An introduction to the Methods of Optical Crystallography. Holt, Rinehart and Winston, New York, 1960, at 25.

B. What properties can be measured by Polarized Light Microscopy?

The incorrect identification of talc particles as chrysotile would have been evident if all optical properties of the suspect minerals had been evaluated.

Polarized light microscopy has been used for more than 200 years by mineralogists to identify minerals. Most minerals were originally named and differentiated from other minerals based on their optical properties. There are many properties that can be determined **independently** by polarized light microscopy, and together they provide under most circumstances sufficient information to differentiate one silicate mineral from another. These properties include:

1. Optical group (uniaxial, isotropic or biaxial)
2. Indices of refraction
3. Birefringence
4. Size and sign of the optic axial angle in biaxial minerals
5. Dispersion of the optic axes
6. Orientation of principle indices of refraction and cleavage
7. Color
8. Relief (relative to matrix)
9. Form
10. Sign of elongation (if elongated)
11. Extinction angle (to elongation or cleavage)

All of these properties could have been determined by MAS in their identification of an unknown as chrysotile. In my practice, I use all of the parameters 1-11 to identify minerals by polarized light microscopy.

To the contrary, MAS did not do so. In the MAS reports, there is no mention of the **optical group**, the **optic axial angle**, the **dispersion of the optic axes**, the **orientation of the principal indices of refraction and cleavage**, or the **mineral color**. Furthermore, as I will explain, although the information on measuring the **birefringence** independent of the measurement of indices of refraction is possible, MAS did not make this measurement. In simple terms, birefringence is the difference in the indices of refraction of parallel and perpendicular to elongation. Instead, MAS derived a birefringence from the indices of refraction it reports. Had MAS measured birefringence independently, it would have been clear that the **indices of refraction it reports are incorrect**. Although MAS reports that some of the particles are fiber bundles, this **form** is not consistent with the evidence provided. MAS did determine the **sign of elongation** as it is the same for both chrysotile and talc, and for that reason, I will not discuss that property further. Many minerals have a positive sign of elongation. Talc usually has a slight **angle of extinction (about 10 degrees)** but there is no evidence to indicate that MAS ever measured this angle precisely.

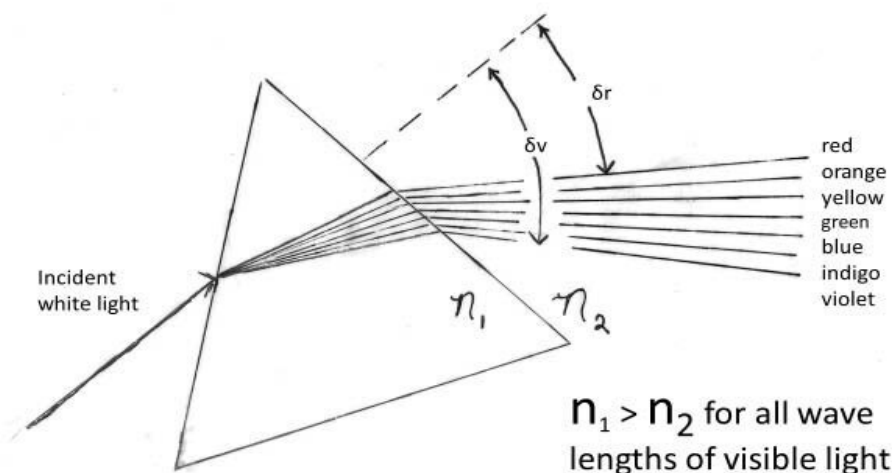
Although MAS did not utilize the full capabilities of polarized light microscopy in the incorrect identification of talc particles as chrysotile, the MAS reports provide enough raw data to differentiate chrysotile from talc and other materials in talcum powders.

C. Dispersion staining, dispersion of the index of refraction and λ_0 .

MAS incorrectly interpreted the dispersion staining colors to derive an index of refraction. The correct interpretation of the dispersion staining colors would result in indices of refraction that are inconsistent with chrysotile but consistent with talc.

The MAS conclusion that identifies a particle as chrysotile is mainly based on the particle's indices of refraction, determined by dispersion staining, and a birefringence calculated from the indices of refraction. MAS's raw data come from central stop dispersion staining images, showing colors parallel and perpendicular to the particle's elongation. MAS's mistakes stem from two issues: first, using colors from dispersion staining with only one immersion oil (usually 1.550 Series E, sometimes 1.560 Series E) instead of the recommended two or three⁴; and second, making unfounded extrapolations to a reference index of refraction. To clarify these errors, I will briefly explain how dispersion staining functions.

Figure 2. What is dispersion?



In **Figure 2**, light enters a glass prism from the left at an angle to the surface. If the indices of refraction of the solid (n_1) are different from the surrounding medium (n_2), the light rays will be bent. Because white light is composed of a range of wavelengths (from about 400-700nm) light of different wavelengths travels through this solid at different speeds, and they are bent. Because of this, they travel along different paths. When they emerge on the right side, the colors (wavelengths) of visible light are separated. This is called dispersion.

⁴ Bloss, F. Donald, Optical Crystallography. MSA Monograph Series 5. Mineralogical Society of America, 1999, at p.55.

Figure 3. Illumination by monochromatic light (from Bloss 1999⁵)

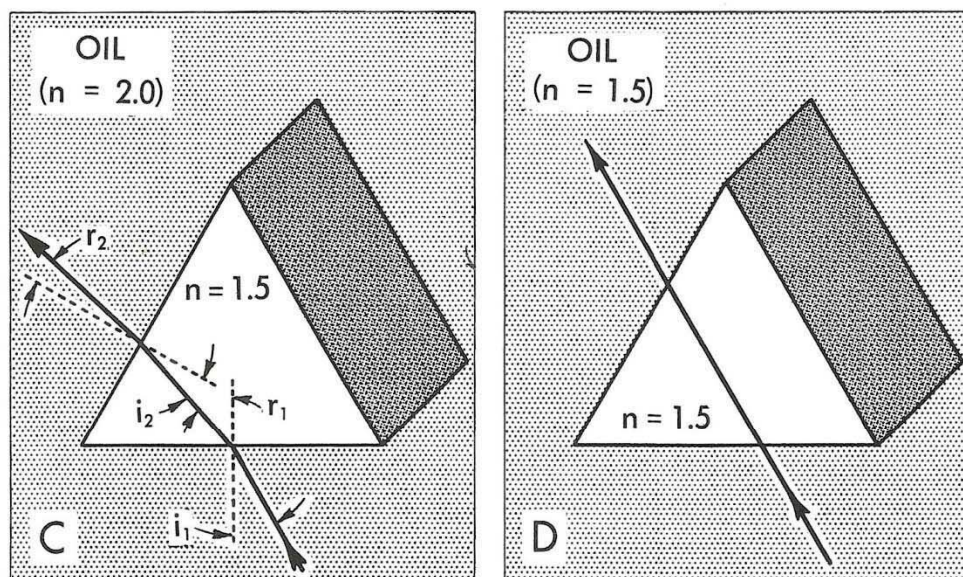
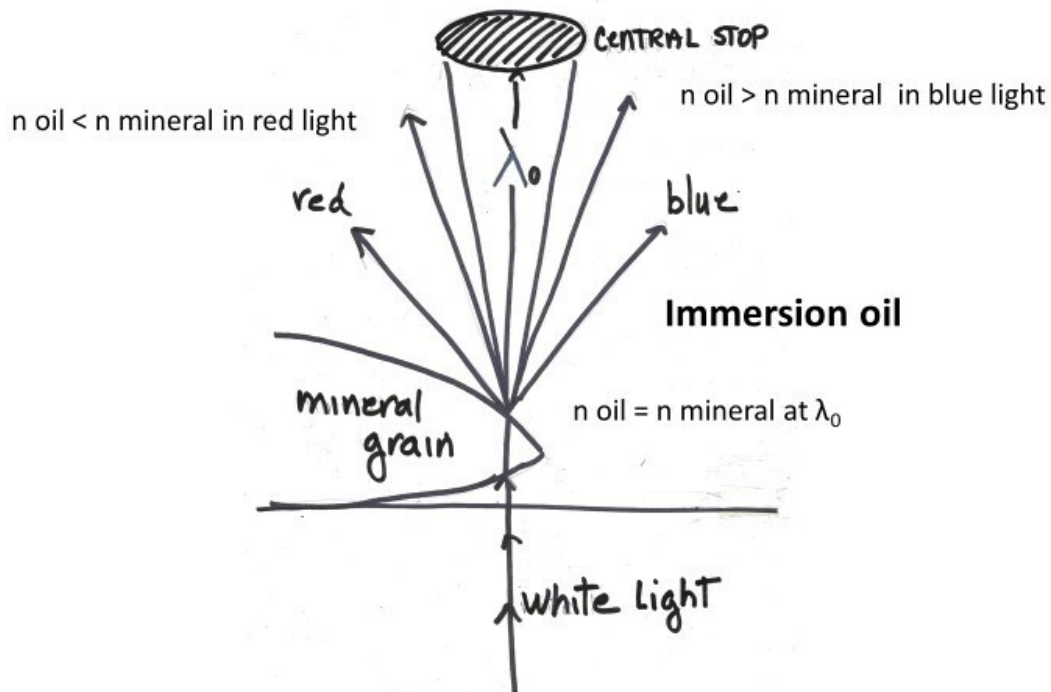


Fig. 2-3. Successive refraction of a light ray by two parallel interfaces (A) and by two nonparallel interfaces (B), (C), or (D). The front half of each glass solid has been removed to expose the plane of incidence. In (C) the glass prism is immersed in an oil of larger index than the glass; in (D) the glass and oil have identical indices.

In **Figure 3**, the prism is illuminated by light with only a single wavelength, unlike white light, which contains multiple wavelengths. On the left, how much the light bends depends on the angle it hits the prism, labeled i_1 , and the difference in how fast light travels through the prism versus the air or oil around it. On the right, because the light speed inside the prism and in the surrounding medium is the same at this wavelength, the light does not bend.

These simple concepts can be used to understand how dispersion staining works. In **Figure 4**, white light illuminates a mineral grain that is sitting on the microscope stage. In this example, the mineral and the immersion oil in which it sits have the same index of refraction at a wavelength labeled λ_0 . For red light, the index of refraction of the oil is less than the index of refraction of the mineral and in blue light the opposite is the case. For this reason, the ray paths for red light and for blue light are bent and diverge.

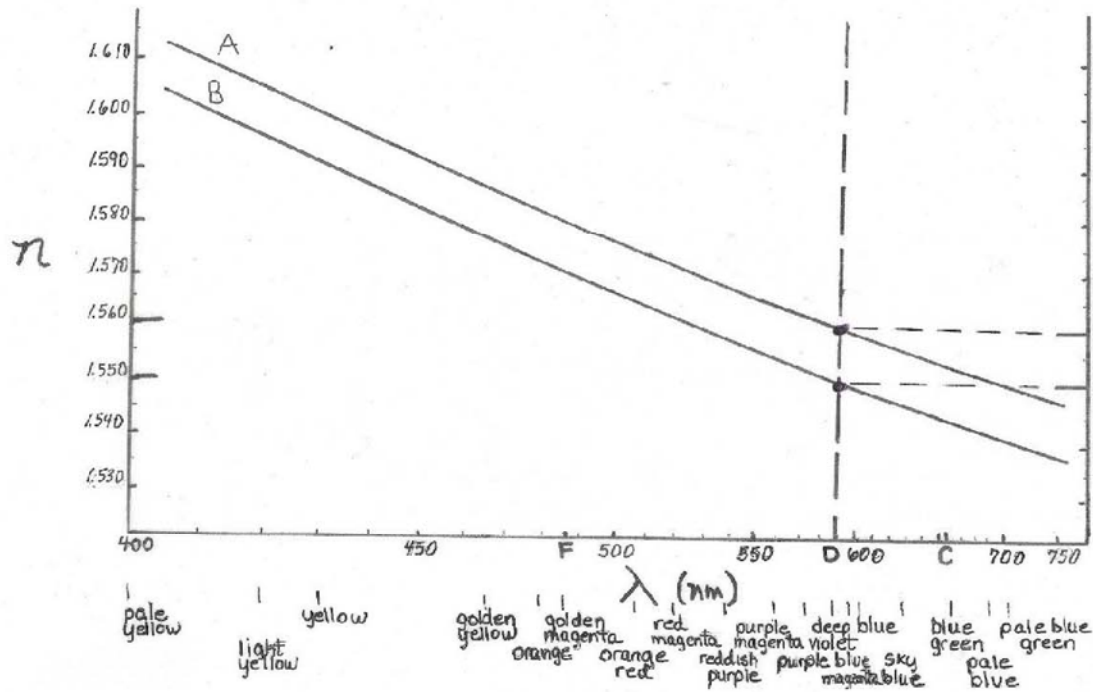
⁵ Bloss, F. Donald, Optical Crystallography. MSA Monograph Series 5. Mineralogical Society of America, 1999, Figure 2.3 p.11.

Figure 4. Dispersion staining and λ_0 .

In central stop dispersion staining, an opaque disc is placed on the back of the microscope objective in the center, blocking all light that cannot be bent around it. For minerals, the center of the grains normally is black, because the angle of incidence is near zero (90-degree angle) and when that is the case, even when the indices of refraction of grain and mineral are different, there is no bending. For the same reason, in the field of view without particles, the light is also blocked by the central stop and appears black. However, on the grain edges, color appears if some of the visible light is removed by the stop. The wavelength removed is that for which the index of refraction of the mineral and oil are the same, because at that wave length light does not bend. The matching wavelength is referred to as λ_0 . In the example shown in **Figure 4**, λ_0 is at a wavelength near the center of the spectrum of white light, so the color along the edges would be seen as purple as the red and blue bend around the central stop and then are combined by the objective when the image is formed. This is the origin of the “stain” in dispersion staining. It is not a stain like coffee on a white blouse, which is a pigment stain. It is a color that depends on the wavelength of λ_0 , and λ_0 is controlled by the index of refraction of the mineral and the oil in which it is immersed. For a dispersion staining color to be visible, the index of refraction of the mineral and the oil must be the same at some wavelength within visible light.

When observing this phenomenon without the central stop in place, one can see a yellowish line on the grain boundary and just outside of it, a bluish line. These are called Becke lines.

Figure 5. Dispersion of the Series E oils and D, the wave length of reference. Data from Cargille⁶, the manufacturer of the oils.

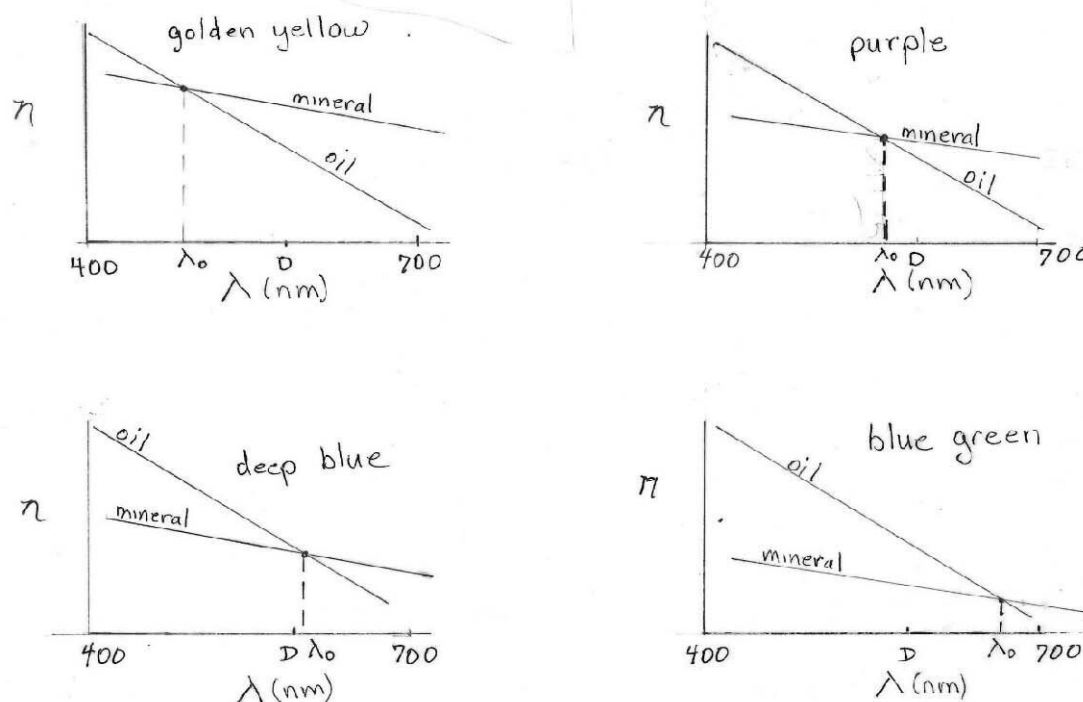


In **Figure 5**, the index of refraction (n) is plotted on the vertical Y-axis, while wavelength is on the horizontal X-axis. This figure also gives along the X-axis the dispersion staining colors observed at specific wavelengths for λ_0 . The two oils, A and B, display a broad variation in their indices of refraction across different wavelengths, known as their dispersion. This dispersion is indicated on the Cargille oil bottles as $n_F - n_C$, representing the difference between the indices of refraction at two other reference wavelengths, F and C, which are highlighted in the figure.

For all minerals and oils, the “index of refraction” on the label or in reference texts is the index at a particular wavelength of reference, referred to as the D line. (There are a number of wavelengths missing from the sun’s spectrum, labeled, A, B, C... and this is the D wavelength.) D corresponds to a wavelength of 589 nanometers. When we look up optical data in a table of mineral data, what are given are the values at the D wavelength. When MAS says that the index of refraction of a mineral particle is 1.562, that refers to the index at the D wavelength. The two oils used by MAS are labeled 1.550 and 1.560 because the index of refraction of those oils have these values at the D wavelength.

⁶ Cargille, Refractive Index Liquids, available at <https://www.cargille.com/refractive-index-liquids/>.

Figure 6a. Dispersion of the indices of refraction of oils and minerals and the central stop dispersion staining colors



In **Figure 6a**, I have shown the variation of wavelength for a mineral and four different oils such that at some wavelength in the visible the two are equivalent. That wavelength is labeled λ_0 . You will notice that the dispersion of the oil (change in index of refraction with wavelength) is always greater than that of the mineral. This is a general principle and the oils are formulated to ensure that this is the case. If λ_0 occurs in the blue end of the spectrum so that some of the blue light is removed by the central stop on the back of the objective, then the “stain” will be yellow. If the matches are near the D line, the colors will be purple when the match is just below the D line and deep blue when it is close or just above D. Sometime, when the particles are small, the stain colors will be hard to see if λ_0 is close to the D wavelength. When the match is in the red end of the spectrum, the staining colors will be blue green.

In this figure, I have shown a mineral with a fairly strong dispersion, i.e., the slope of the line representing the mineral’s index of refraction is less than the oil but still significant. Minerals vary a great deal in how strong their dispersion will be in visible light, i.e., how much the line relating index of refraction to wavelength will slope. This variation is an important property in the interpretation of dispersion staining colors with respect to the value of the index of refraction of the mineral at the reference D w. But one thing that does not vary is the relationship between the dispersion staining color and λ_0 . They are independent of the absolute values of the indices of refraction of either oil or mineral.

Figure 6b. λ_0 Central stop dispersion staining colors.⁶

λ_0	Central Stop Dispersion Staining colors
700	pale blue green (S)
680	pale blue (M)
660	bright greenish blue(B) blue-green(M) lt blue green(S)
625	sky blue(B) blue(M) blue-green(S)
600	blue(M)
595	deep blue(S) blue-magenta(M)
589 D	deep violet (B)
575	purple(B)
560	purple(S) magenta(M)
540	reddish purple(B)
520	red purple(S) red-magenta (M)
505	orange-red(B)
485	orange(S); golden magenta (M)
480	orange(B)
465	bright gold(B)
455	golden yellow(M)
430	yellow(M)
420	light yellow(M)
400	pale yellow(S)

To determine λ_0 , one must identify the dispersion staining color and compare that color to the descriptions given in **Figure 6b**, or one can use a monochromator in the optical system and measure it precisely. In some of the MAS optical data sheets, specific values for λ_0 parallel and perpendicular to elongation are provided; in others, one can only estimate the value of λ_0 from the color in the photograph.

Below, in **Figure 7** I have copied three photographs from three different MAS reports. The first shows a particle 49.6 μm in length that is identified as chrysotile. The rest of the particles in the photograph are not identified, nor are they claimed to be chrysotile. They are talc. There are several things to note in **Figure 7a**. First, the dispersion staining colors of all the particles are very similar. I would note that they are a bit more orange than I would expect for 1.550 oil, which is either due to the fact that the voltage of the tungsten light source was too low, or a blue filter, which must be present in the optical system to properly interpret the dispersion staining colors, is missing. What is clear, however, is that all particles that have the same dispersion staining colors have the same λ_0 and the same index of refraction at λ_0 . Based on the chart of colors, the yellow colors indicate that λ_0 is in the blue end (about 440nm) of the spectrum. Note also that the other prominent color in some grains is a bright sky blue. These grains are oriented so that for them, λ_0 is in the red end of the spectrum (about 640 nm). There is some uncertainty in the estimates due to color interpretation (**Figure 6**) and to experimental conditions discussed later, e.g., temperature.

⁶ M is from The Asbestos Particle Atlas written by Walter McCrone, published by Ann Arbor Science, Ann Arbor Michigan 1980. Table 4, P. 25.

S is from Shu-Chun, Su., A rapid and accurate procedure for the determination of refractive indices of regulated asbestos minerals, American Mineralogist 88:179-182, 2003, Table 2 p.1981.

B is from Bloss, F. Donald, Optical Crystallography. MSA Monograph Series 5. Mineralogical Society of America, 1999, Table 5.1 p.55.

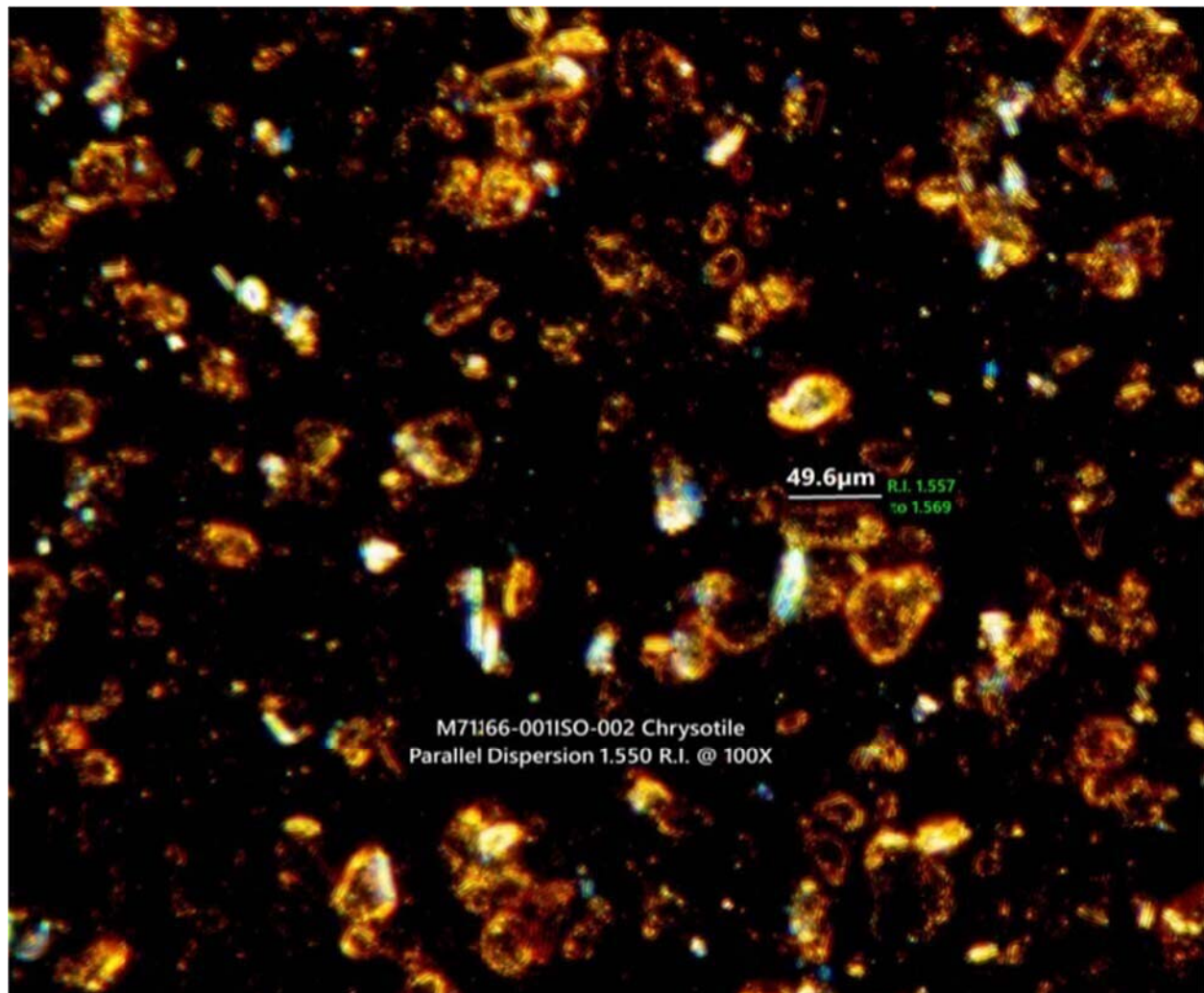
Figure 7a.

Figure 7b.

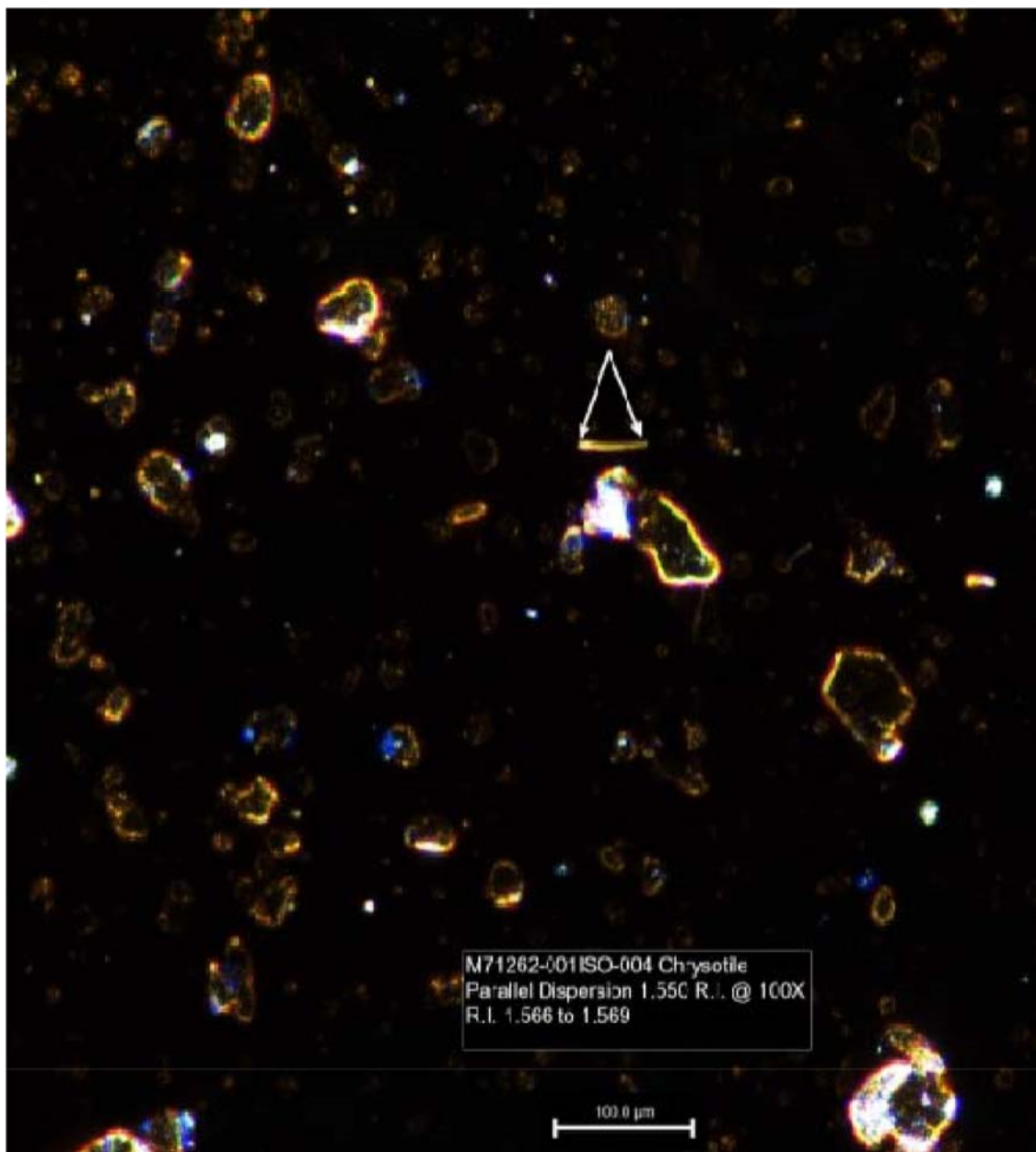


Figure 7b was taken of a different sample at a later time by MAS. The colors are now a much clearer yellow, but the same conclusions can be drawn. The particle labeled as chrysotile stains a bright yellow, and so do many of the talc particles, just as was the case in **Figure 7a**. The other color in some of the talc particles is also blue.

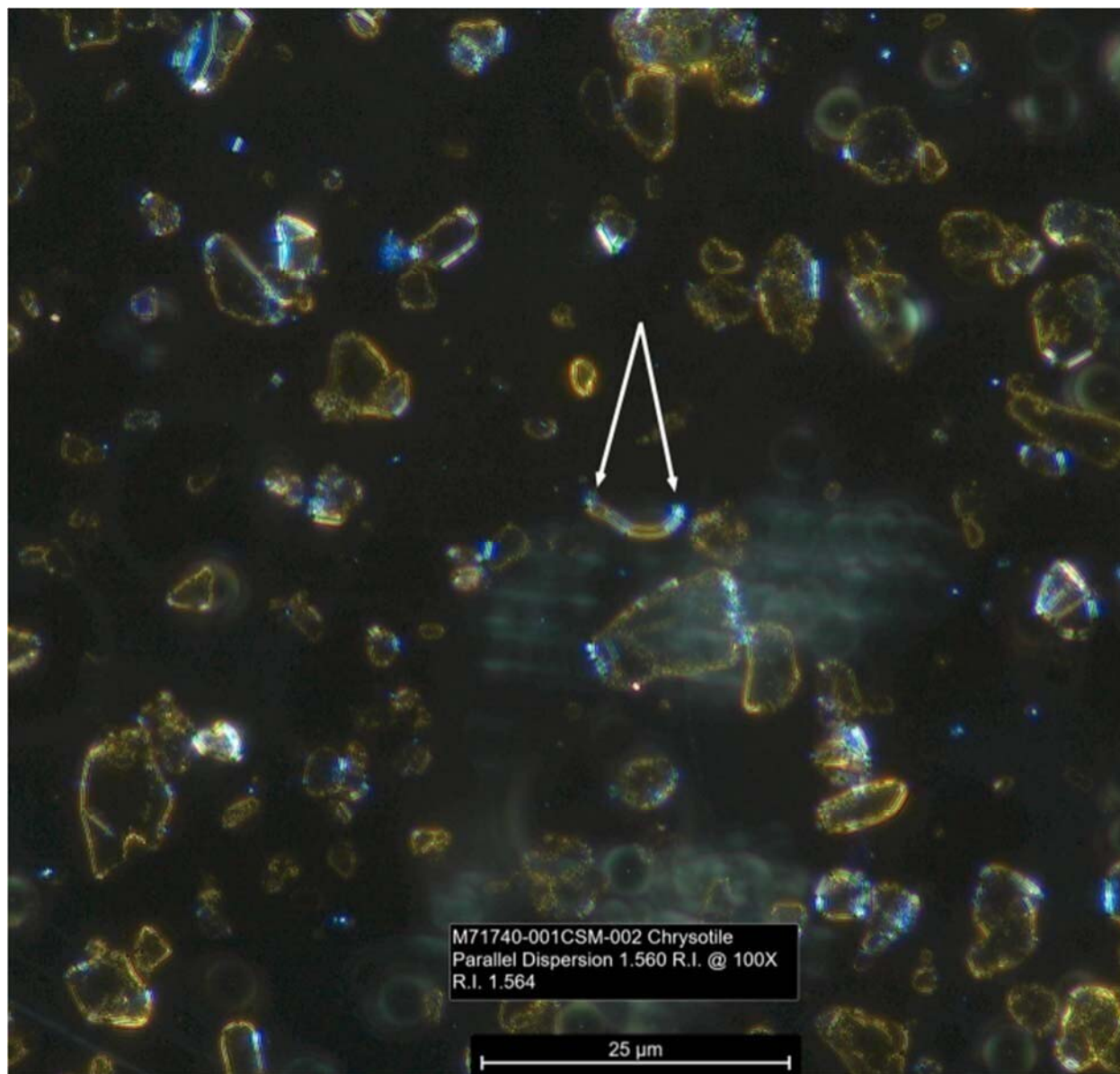
Figure 7c.

Figure 7c was taken in a different oil, 1.560 Series E. The yellow colors of the talc particles are slightly more golden than in Figure 7b, and the blues are slightly bluer green. We would expect slight shifts in λ_0 to the right (higher wavelength) as the indices of refraction of the oil increase from 1.550 to 1.560. In **Figure 7c**, the particle identified as chrysotile is oriented such that the index of refraction is associated with the ray that vibrates perpendicular to elongation, which has a lower index of refraction than were it oriented parallel to elongation, as the particles were in Figures 7a and b. Again, as was the case in Figures 7a and b, the so-called chrysotile displays the same dispersion staining colors as many of the talc particles, and therefore they have the same index of refraction in 1.560 Series E oil and the same λ_0 .

Our first conclusion from **Figure 7** is that talc and “chrysotile” are not distinguished from each other by MAS by dispersion staining colors. In my opinion, this is because the particles identified as chrysotile are not chrysotile at all. The particles should be objectively identified as talc, and not chrysotile, because they are identical to other talc particles in the samples, and there is no scientific data that would suggest otherwise. Other examples of the dispersion staining colors of talc and the particles MAS indicates are chrysotile are provided in Appendix 1.

D. How do derive an index of refraction at the D wavelength from a dispersion staining color?

A major error MAS makes is the relationship between the dispersion staining colors (λ_0) and the index of refraction at the D wavelength of reference.

For reference, in **Figure 7a** MAS reports the index of refraction parallel to elongation at the D wavelength for the identified particle as 1.557-1.569; for the particle in **Figure 7b**, MAS reports 1.566-1.569 parallel to elongation, and for the particle in **Figure 7c**, perpendicular to elongation, MAS reports 1.564 as the value at the D wavelength. In my opinion, the colors in **Figures 7a** and **7b** (also shown in Appendix 1) are indicative of a mineral with an index of refraction closer to 1.586 parallel to elongation. Because the colors in **Figure 7c** are blue green, the mineral must have a lower index of refraction perpendicular to elongation than the oil, which in this case is 1.560. In other words, the index of refraction cannot be 1.564 and stain blue in 1.560 oil as MAS asserts.

So, we might ask, how do I know that a yellow color means that the index of refraction at the D line is closer to 1.586 than it is to 1.566 and why can't a mineral that stains blue in 1.560 have a higher index of refraction than 1.560?

To explain that, I will analyze carefully the dispersion staining color shown in **Figure 8**.⁷ **Figure 8** shows a particle that is 34.1 μ m in length immersed in oil nD = 1.550 Series E and identified as chrysotile by MAS. In **Figure 8a**, the particle is oriented so that the polarizer constrains the light to vibrate parallel to elongation, and in **Figure 8b**, the particle has been rotated 90 degrees so the light vibrates perpendicular to elongation. Parallel to elongation, the dispersion staining color is yellow and perpendicular the color is blue green. Note also, as was pointed out in **Figure 7**, the talc particles stain the same colors, indicating the same index of refraction at λ_0 .

⁷ Although only one photomicrograph is discussed in this section, most of the particles identified as chrysotile show dispersion staining colors that are similar. Other examples can be found in Appendix 1.

Figure 8a.

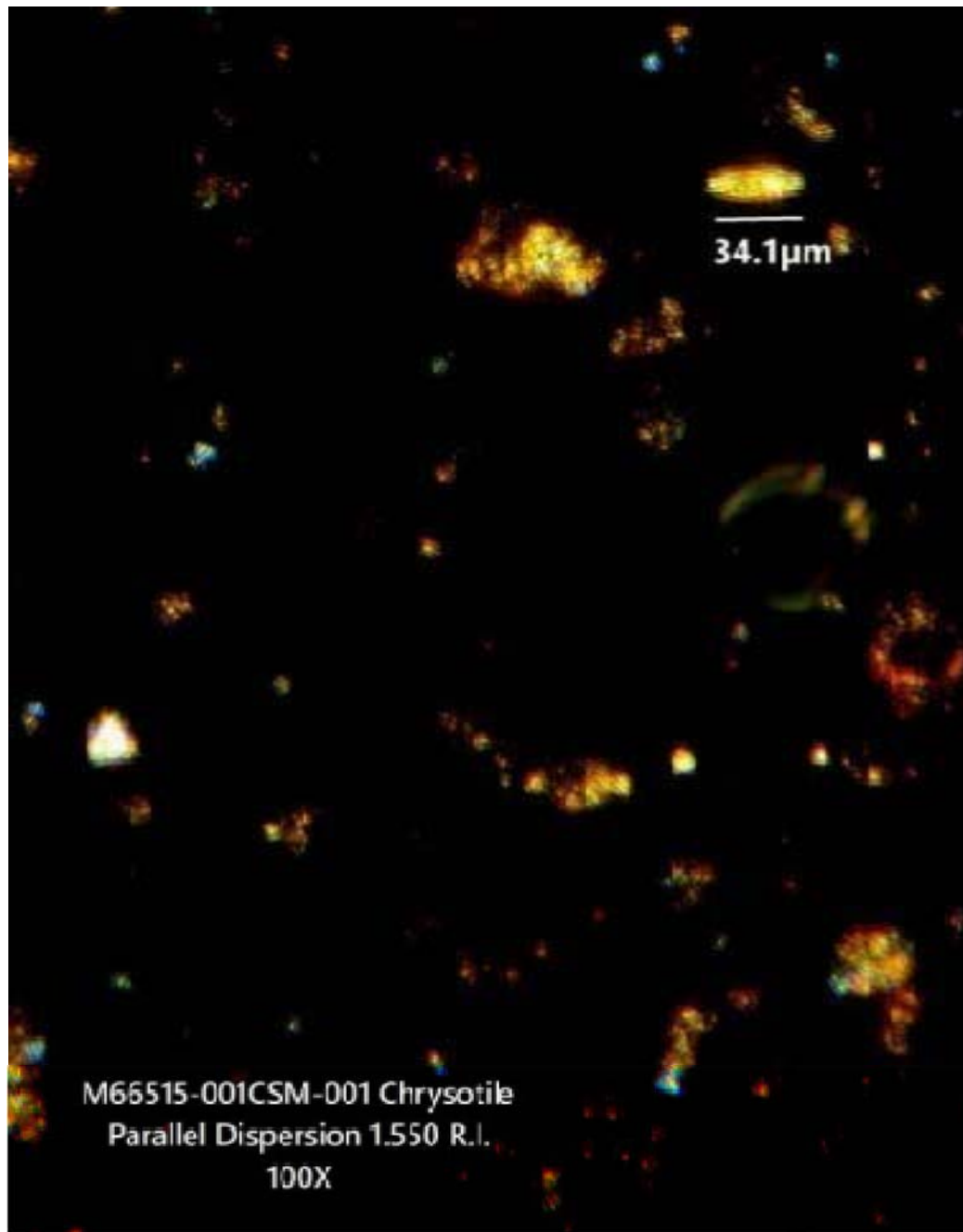
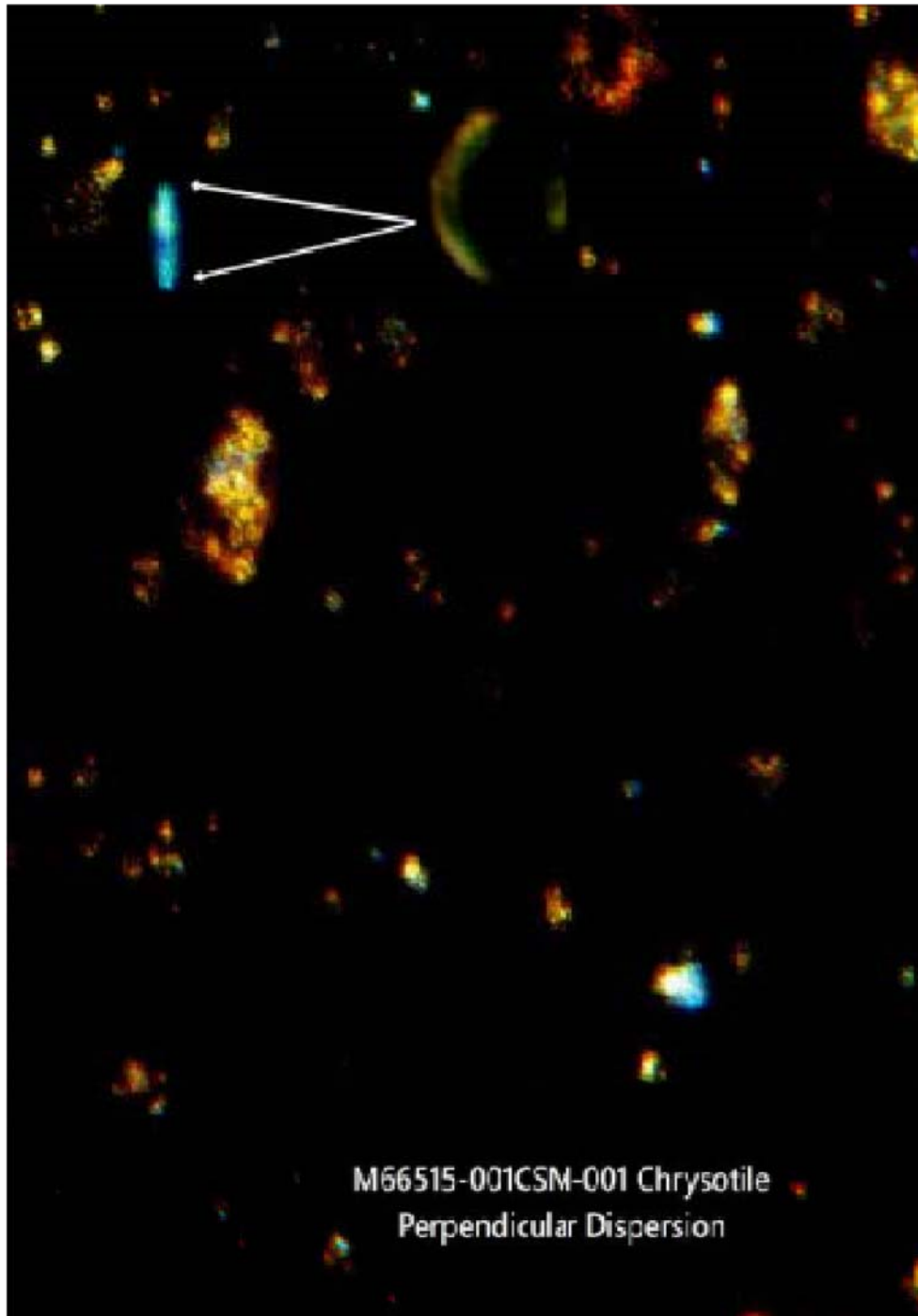
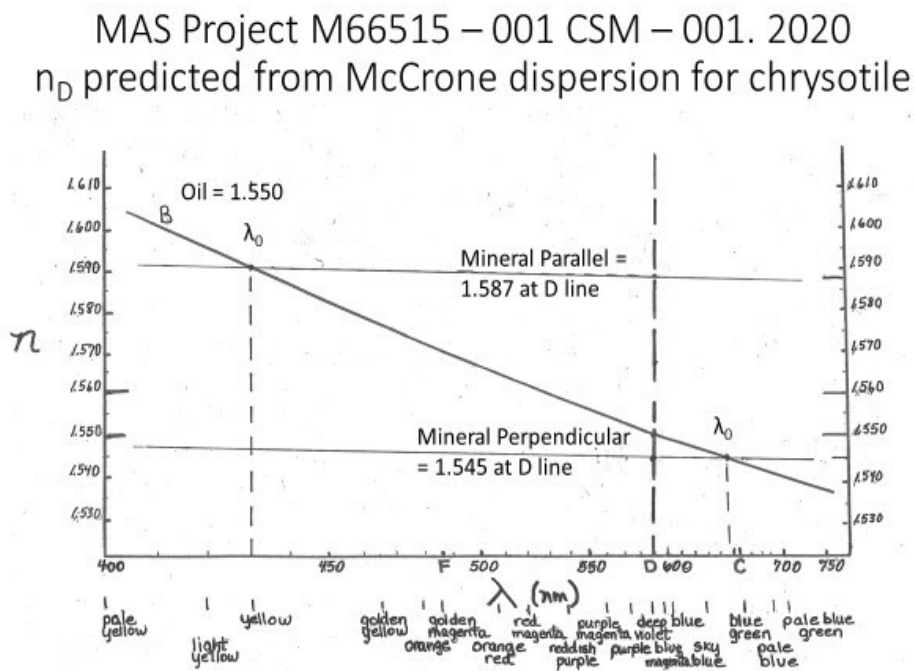


Figure 8b.



In **Figure 9**, I have plotted the dispersion for 1.550 Series E oil and the observed λ_0 for a particle shown in **Figure 8**, both parallel and perpendicular to its elongation. For the particle in **Figure 8**, λ_0 is around 430 nm parallel and about 645 nm perpendicular to elongation. I drew a line from λ_0 to the D line in both orientations, slightly off horizontal. This approach is based on dispersion data for chrysotile from Walter McCrone, who popularized dispersion staining for identifying commercially mined asbestos. McCrone's data show that the dispersion of chrysotile's refractive index is 0.003 parallel and 0.001 perpendicular to elongation.⁸ Assuming this dispersion, the indices of refraction estimated for this particle at the D line are 1.587 parallel to elongation and 1.545 perpendicular. These indices of refraction would not correspond to indices of refraction required for chrysotile identification. MAS incorrectly reported different indices for this particle.

Figure 9. Data on dispersion of chrysotile from McCrone⁷

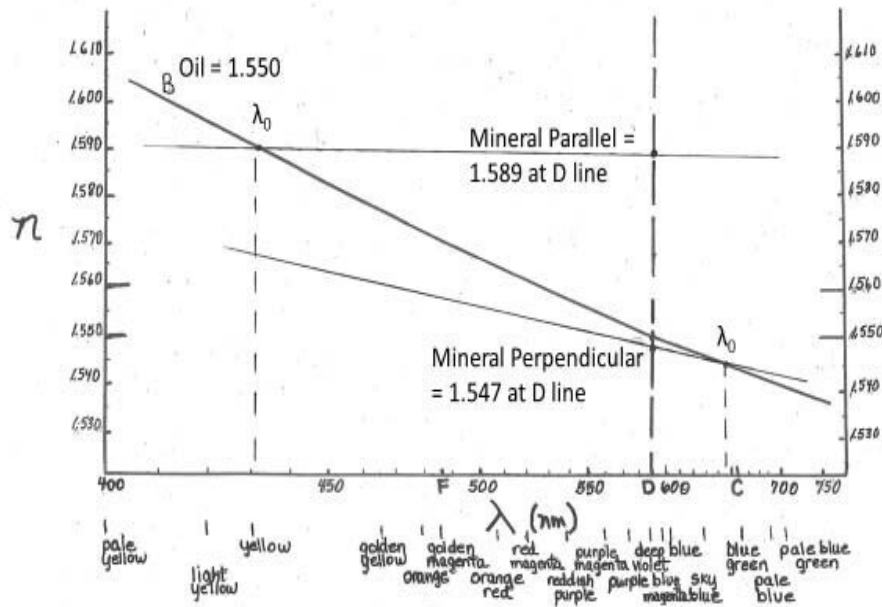


⁸ McCrone, Walter. Undated Determinative Tables and Charts supplied with the McCrone Dispersion Staining Objectives. Published by Walter C McCrone Associates, Chicago Illinois as the Particle Analyst's Handbook.

Could this particle then be talc? McCrone also provides the dispersion of talc parallel and perpendicular to elongation and those data are plotted in **Figure 10**.

Figure 10.

MAS Project M66515 – 001 CSM – 001. 2020. n_D predicted from McCrone dispersion for talc. λ_0 at 430 and 645 nm.



According to McCrone, the dispersion of the index of refraction of talc parallel to elongation is very small with $n_F - n_C = 0.001$, so this curve is almost flat. On the other hand, perpendicular to elongation the dispersion is quite high. By using the dispersion of talc, the indices of refraction of this grain can be estimated as 1.589 and 1.547.

MAS reports the indices of refraction of this grain as 1.557 to 1.569. **There is no explanation of how MAS uses an observation of a single dispersion staining color in a single oil to derive the value of the index of refraction at the D line.** One must know either the dispersion of the mineral to begin with, hence it is not an unknown, or follow the guidance of the textbooks on dispersion staining for mineral identification, which requires observations of dispersion staining colors in two or more oils.

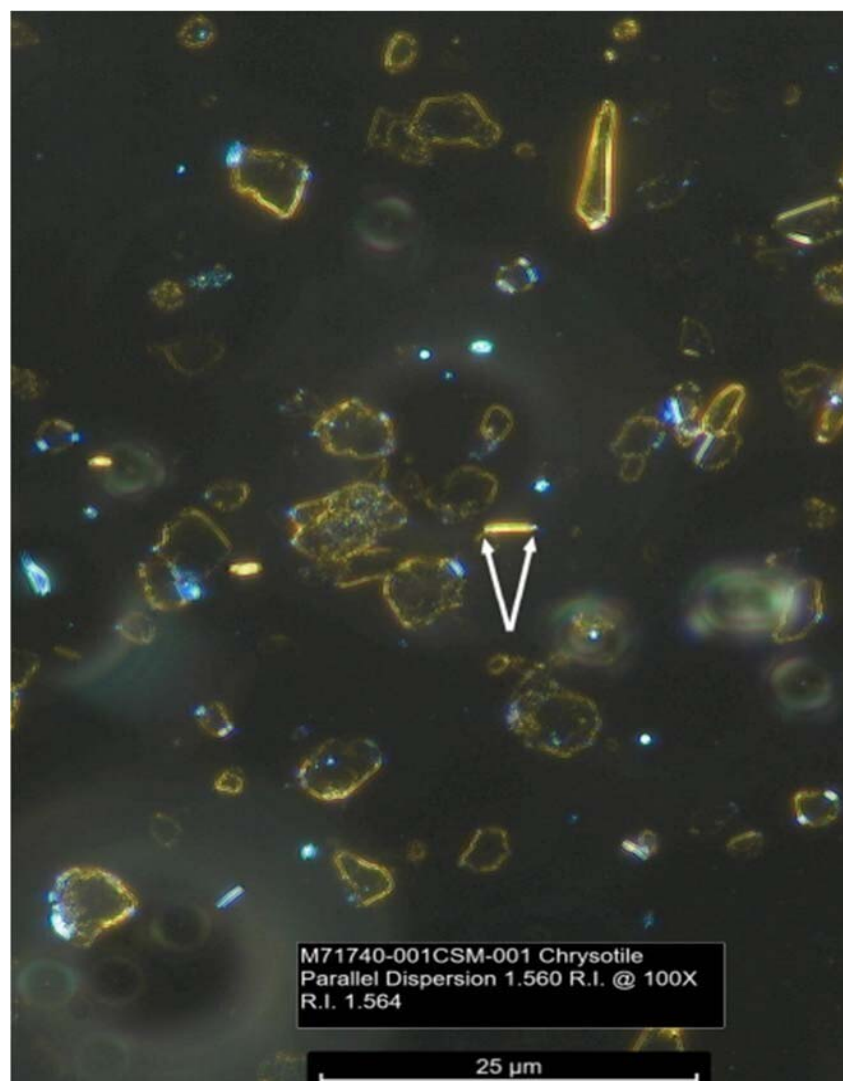
E. Determining n_D from observations in two oils.

Had MAS used more than one immersion oil, λ_0 parallel and perpendicular could have been used to determine n_D without knowing the dispersion. Not doing so is inconsistent with standard practice in the identification of an unknown.

We can use the dispersion staining colors MAS reports parallel to elongation in Series E oils 1.550 and 1.560 to test the hypothesis that the dispersion of the particles identified as chrysotile is very small, without knowing the mineral or assuming its dispersion.

In **Figure 11** below, the dispersion staining colors of the MAS identified “chrysotile” in oil 1.560 Series E are shown.

Figure 11. Dispersion colors parallel to elongation

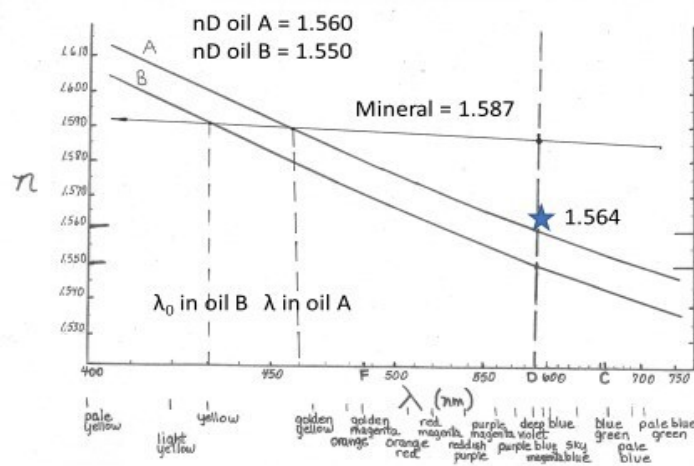


The dispersion staining colors have changed very little from those observed in 1.550 and λ_0 remains within the yellow range. MAS interprets this color as arising from a mineral with $n = 1.564$. However, the fact that the colors have changed very little makes this conclusion impossible because the dispersion curve must be fairly flat, as **Figure 12** shows.

In **Figure 12**, the λ_0 's observed parallel to elongation in oils 1.550 and 1.560 are plotted.

Figure 12. Two λ_0 s from two oils fix the mineral dispersion.

Observations in Oil A from Valadez Bot 2.28.23 and Oil B from AS Project M66515 – 001 CSM – 001. 2020: The dispersion curve parallel to elongation



The dispersion curve of the unknown must be flat to explain the fact that the observed dispersion staining colors change very little in the two oils. There is no reasonable explanation for the conclusion MAS makes that this mineral has an index of refraction of 1.564, which would require a dispersion approaching that of the oils.

In summary, the extrapolation from the observation of the dispersion staining colors in a **single** oil to a value of the index of refraction at the reference wave length cannot be made unless the dispersion of the mineral is known in advance. In this case, both talc and chrysotile have low dispersion and the indices of refraction MAS derived from the dispersion colors are inconsistent with its own observations. When the mineral is examined in two different oils, it is clear also that the MAS-reported indices of refraction are inconsistent with the data provided. Furthermore, the dispersion staining colors are indistinguishable from talc. In fact, the so-called chrysotile is actually talc.

F. Birefringence

MAS reports birefringence by subtracting the index of refraction it reports perpendicular to elongation from the index of refraction it reports parallel to elongation. Given that the indices of refraction are incorrect, this yields incorrect estimates of the birefringence. Alternate approaches to determining birefringence should have been used.

Although MAS did not consider an alternate approach to birefringence, as I mentioned early in this report, birefringence can be estimated *independently* from the values of the indices of refraction by an examination of the **retardation** observed when the mineral is in the 45-degree position and the second polarizer, the analyzer, is in the optical path and the central stop has been removed from the optical path⁹.

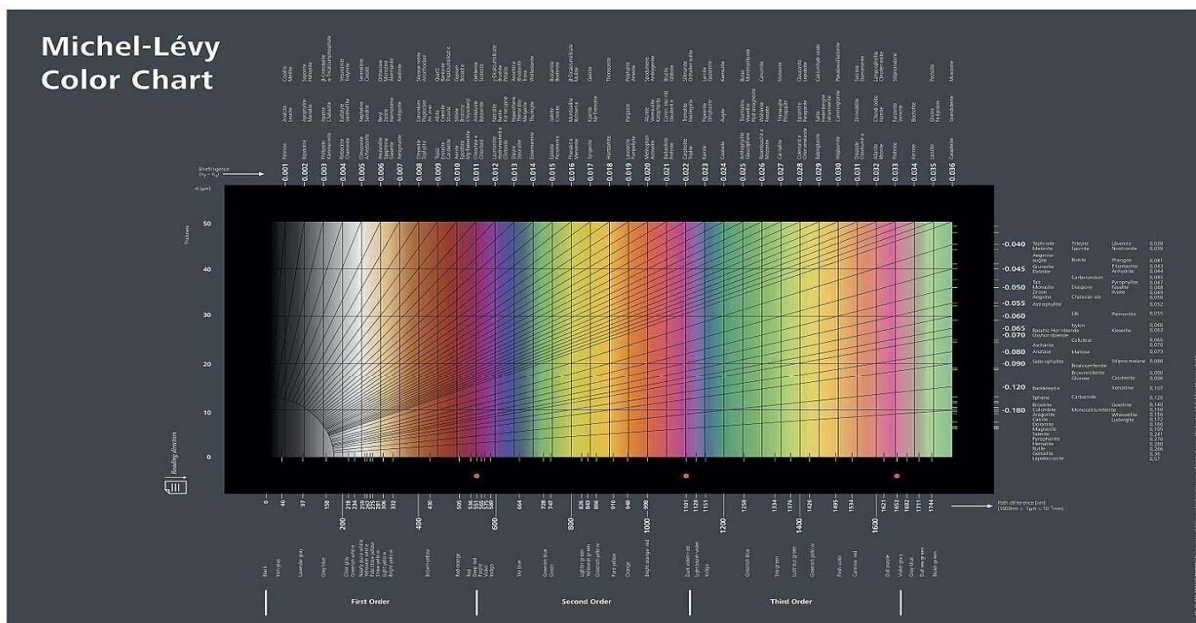
Retardation is a measure of the distance separating two rays that have travelled through the mineral at different speeds when they emerge from the mineral particle, one vibrating parallel to elongation and one vibrating perpendicular to elongation within the mineral. This distance, measured in nanometers, is a function of the speed of each ray, (i.e., index of refraction), and the distance of travel, which is the thickness of the mineral particle. This relationship is related by a simple formula.

$$\text{Retardation} = \text{thickness} (n_{\text{parallel}} - n_{\text{perpendicular}})$$

When the rays emerge, they combine and interfere, producing a color (like an oil sheen on water) called an interference color. Fortunately, all optical textbooks provide a chart, which I have reproduced in **Figure 13**. In this chart, the interference colors are shown. The distance separating the rays when they emerge is on the X axis, thickness on the Y axis and the interference color that corresponds to the retardation is shown. The radiating lines represent different amounts of birefringence.

⁹ Bloss, F. Donald, Optical Crystallography. MSA Monograph Series 5. Mineralogical Society of America, 1999, at p.117 and following.

Figure 13. The Michel Levy chart relating thickness, retardation, interference colors and birefringence.



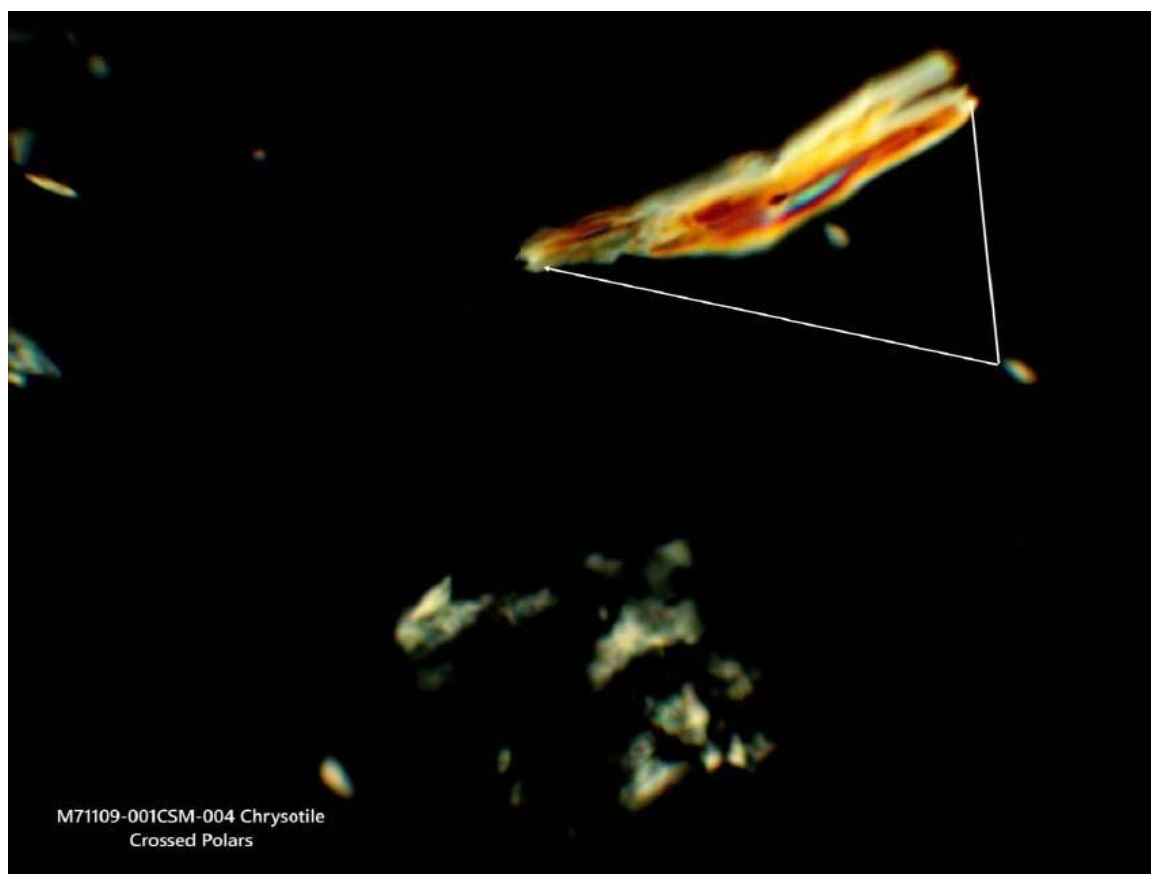
Carl Zeiss Microscopy GmbH
microscopy@zeiss.com
www.zeiss.com/microscopy



We make it visible.

The interference colors of particles that are very thin are hard to interpret because they are simply shades of grey, no matter how high the birefringence is, but in the MAS reports, there are many particles large enough that the birefringence can be estimated from the photographs provided. An example is shown in **Figure 14**. Other examples are provided in Appendix 2.

Figure 14. Particle identified as chrysotile in the 45-degree position with the polarizer and analyzer in the system.



The particle shown, identified as chrysotile by MAS, is 82.2 μm long. It is about 16 μm wide. While we do not know exactly how thick it is, it is likely somewhat less than 16 μm at its thickest point. The interference colors increase from the thin edges to the thickest middle, ranging from grey to Second Order blue, which from the Michel-Levy chart tells us that the retardation is about 650 nm. This means that the fast ray leaves the crystal 650 nm ahead of the slower ray. If this particle has a thickness equal to width, the interference colors require that the birefringence be at least 0.04. If it is thinner, the birefringence would be higher. A material with this birefringence cannot be chrysotile because the birefringence of chrysotile observed in samples from many locations is always < 0.017 .¹⁰ However, it is consistent with the birefringence expected for talc, which at its maximum is ≈ 0.05 .¹¹ Had MAS evaluated the retardation of the particles it identified as chrysotile independently from the indices of refraction, it would have seen that the birefringence it derived from the indices of refraction was incorrect. Other examples are shown in Appendix 2.

¹⁰ Deer, WA, Howie RA and Zussman J, Rock Forming Minerals Volume 3B second edition: Layered Silicates excluding micas and clay minerals. The Geological Society London, 2009.

¹¹ As is discussed later, orientation will affect the observed birefringence in talc. Parallel to elongation, the birefringence can range from < 0.01 up to 0.05. The talc particles MAS calls chrysotile are oriented in such a way that the birefringence is on the higher side.

G. Variation in the indices of refraction determined for the particles identified as chrysotile.

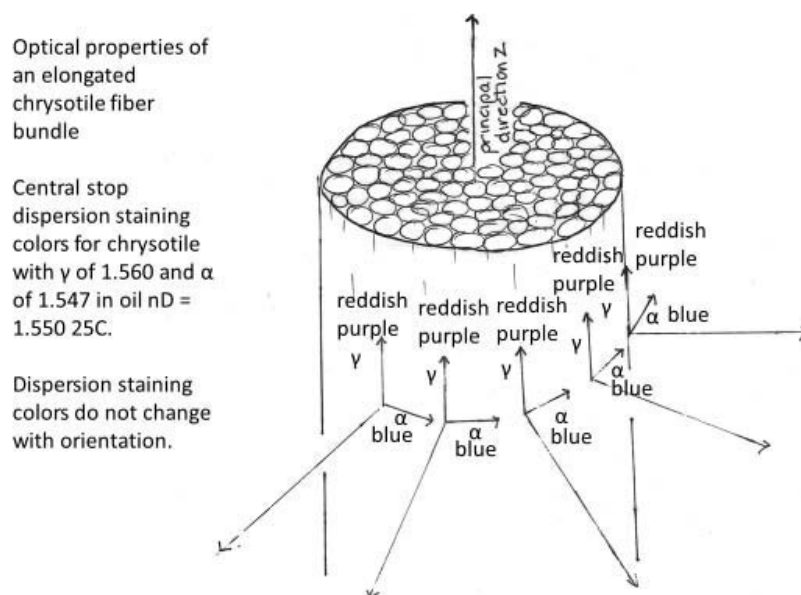
MAS incorrectly assumes that the indices of refraction of chrysotile can vary significantly in a single occurrence. Variations in index of refraction in chrysotile are due to variations chemical composition which are not known to occur in a single location.

In the MAS reports, a repeated claim is made that the variation in the indices of refraction observed and reported for the particles identified as chrysotile is consistent with the mineralogical literature for chrysotile (see, for example, the lab sheet shown in **Figure 19**, Comment section at the bottom). There are two reasons that particles of a single mineral can show a variation in index of refraction: particle orientation and variation in chemical composition. I will discuss these two independently as they apply to chrysotile and talc.

a. Orientation

Figure 15 is a schematic drawing of a bundle of chrysotile fibrils. Chrysotile occurs in nature in remarkably similar ways in all occurrences as bundles of single parallel cylindrical fibrils. Fibrils are tubes formed from cylindrical silicate sheets, commonly with an outer diameter of 0.025 to 0.030 μm and an internal diameter of about 0.005 μm . These individual fibrils are too small to see by light microscopy, so any visible particle of chrysotile will be composed of hundreds of parallel fibrils in bundles. Because of this, chrysotile particles will show no variation in dispersion staining colors perpendicular to elongation due to orientation.

Figure 15. Schematic view of a chrysotile fiber bundle showing consistency of dispersion staining colors with orientation.

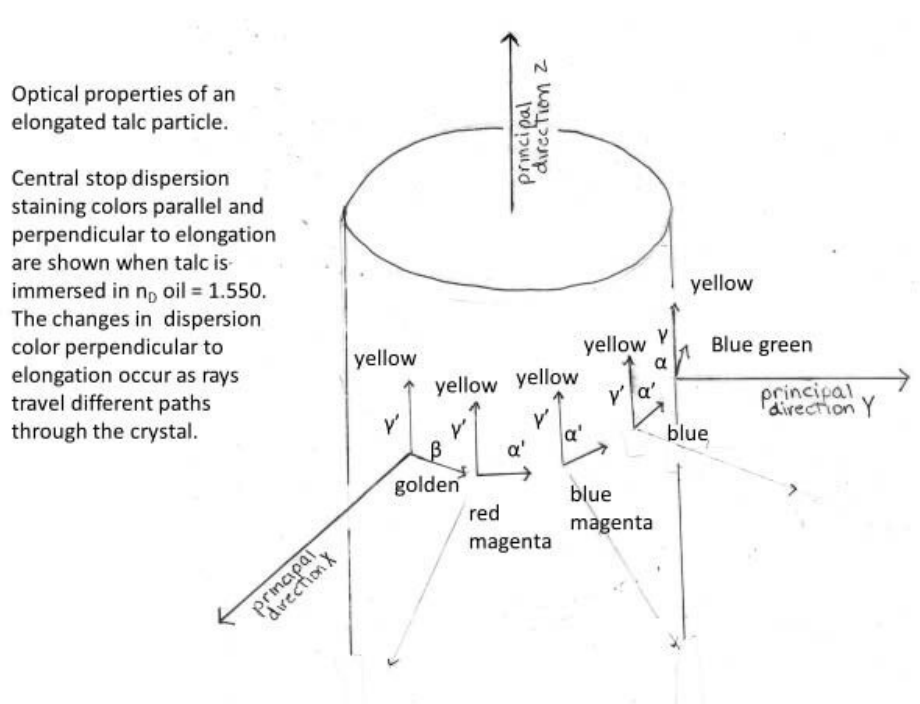


In contrast to chrysotile, **Figure 16** shows an elongated talc particle and the dispersion staining colors in Series E oil 1.550 parallel and perpendicular to elongation, ignoring in this case the small extinction angle normally present.

As **Figure 16** shows, the indices of refraction and associated dispersion staining colors of elongated talc particles perpendicular to elongation change significantly depending on how the particle is oriented. Because talc sometimes has a plane of weakness perpendicular to the direction Y, many will stain shades of blue perpendicular and yellow parallel to elongation, just as MAS reports for its “chrysotile” particles. A few of the particles identified as chrysotile stain reddish purple, indicating a slightly different orientation (See for example MAS 71109-71111)

It is common practice among optical mineralogists when observing particles immersed in oils to “tap the slide” to encourage particles to rotate around the long axis and to change orientation. In this way, if there are changes in dispersion staining colors as a function of orientation it is clear. This technique would have made the distinction between talc and chrysotile evident. There is no evidence that this simple technique was used. Instead, MAS assumed that variation in chemical composition accounted for the observed variation in dispersion staining colors.

Figure 16: Dispersion staining colors and orientation: Talc with principal indices of refraction of 1.588 (gamma) and 1.547 (alpha)

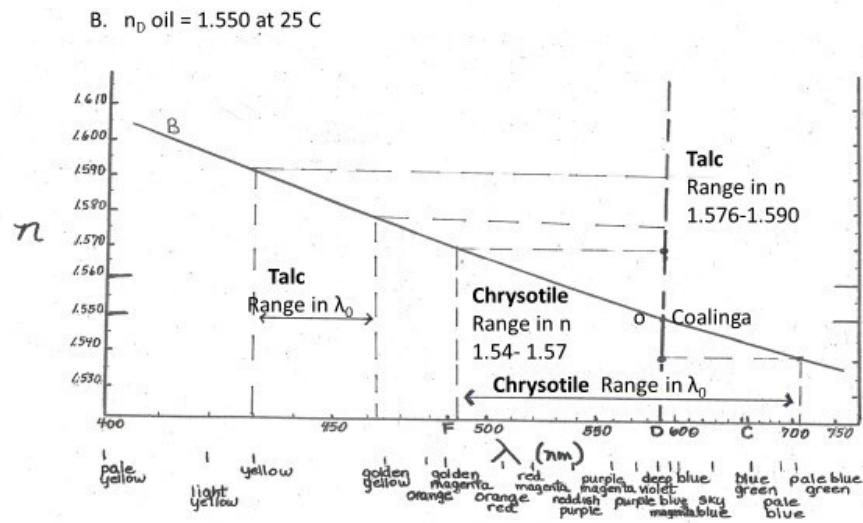


b. Chemical composition

The ideal chemical formula for chrysotile is $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ and the ideal chemical formula for talc is $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. Small amounts of other elements substituting for magnesium (Mg) or silicon (Si) will change the optical properties. The most common substitution with a significant effect on the indices of refraction is iron (Fe). Because like Mg and Si, Fe is a common element, in some occurrences of these minerals it can have a significant impact. **Figure 17** shows the range in λ_0 and associated indices of refraction for talc and chrysotile parallel to elongation in Series E 1.550 oil due to differences in chemical composition. This figure considers the optical properties from many samples found throughout the world.

Figure 17. Range of principal indices of refraction parallel to elongation in talc and chrysotile due to chemical variability across all locations.¹²

Dispersion staining of talc and chrysotile parallel to elongation:
Variation in indices of refraction reflect composition



The data that are illustrated in **Figure 17** are taken from many different geologic settings. Geologic conditions such as abundances of chemical elements, temperature and pressure are variables from one occurrence to another and result in the variation in composition. In some ways, every rock is unique because of the complexity and variability in the physical and chemical conditions under which they form. However, at each location, these conditions are usually the same, and the compositions do not change within a single location often.

Figure 18 gives the λ_0 in 1.550 Series E immersion oil for chrysotile occurrences throughout the world that was compiled by McCrone and published in his Particle Atlas. No variations are shown because chrysotile does not exhibit chemical variability within a single location that is significant enough to alter its appearance by dispersion staining. Each location has a characteristic composition. The assertion by MAS that the variations it observed are due to chemical variability is not supported by chrysotile from any other source and is directly contradicted by the data of McCrone. It is my opinion that the particles are talc, not chrysotile, and variations in dispersion staining colors can be explained by orientation.

¹² Deer, WA, Howie RA Zussman J, Rock-forming Minerals, Volume 3B. Layered silicates excluding micas and clay minerals. The Geological Society. London, 2009.

Figure 18. λ_0 for chrysotile in 1.550 Series E oil vary only by location from McCrone, 1980¹³.

McCrone Asbestos Particle Atlas Table 5

Location	$\lambda_0 \parallel$	$\lambda_0 \perp$	$\lambda_0 \perp - \lambda_0 \parallel$	Location	$\lambda_0 \parallel$	$\lambda_0 \perp$	$\lambda_0 \perp - \lambda_0 \parallel$
Lake Asbestos Quebec	510	610	100	Pacific Asbestos Corp CA	480	610	130
King Asbestos Corp Quebec	510	510	100	Coalinga CA	590	680	90
Asbestos Corp Quebec	500	610	110	Arizona	600	700	100
Bell Mines Quebec	510	600	90	Venezuela	610	680	70
Johnsons Quebec	500	600	100	Rhodesia	520	620	100
Careys Bradford Quebec	480	590	110	Shabina Rhodesia	480	580	100
Flintkote Quebec	500	610	110	Havelock D & C Rhodesia	490	590	100
Normandie Quebec	570	670	100	Havelock HVL Rhodesia	490	590	100
Reeves Ontario	480	590	110	Havelock VRA Rhodesia	500	630	130
Munro Ontario	560	670	110	Cyprus	600	700	100
Hyde Park GAF Vermont	510	620	110	Zandini Greece	580	680	100
Jeffery Vermont	500	580	80	Yugoslavia	520	590	70
Advocate Newfoundland	510	610	100	Balengero Italy	500	600	100
Newfoundland	590	690	100	Russia	500	600	100
Clinton Creek Yukon	500	580	80	Woodsreef Australia	610	680	70
Cassiar British Columbia	500	580	80				

H. Birefringence observations from λ_0 from McCrone (Figure 18) and MAS data particles identified as chrysotile.

MAS's own data on λ_0 are inconsistent with data on chrysotile from McCrone but consistent with talc.

An important observation from **Figure 18** is that the differences in λ_0 parallel and perpendicular to elongation are small, and no range is provided. Most differences are less than 110 and all are less than 130 nm. This limitation reflects the birefringence of chrysotile: it does not vary with location and it is small. ISO Method 22262-1 for the identification of chrysotile in building materials, which MAS states it follows, specifies that the difference should be no more than 100 nm for chrysotile. The majority of the particles identified as chrysotile by MAS have values of λ_0 parallel – λ_0 perpendicular that vastly exceed this value, and even exceed the highest value given by McCrone from any chrysotile, including Coalinga (also known as Calidria). In many of the MAS laboratory sheets, this is made clear. For example, Figure 19 reproduces two of those sheets. Under the column labeled Optical data, α/δ (nm), in the first the numbers 640 and 450 appear, and in the second, 640 and 450. These are the λ_0 's that MAS determined from the observed dispersion staining colors perpendicular and parallel to elongation of the particle identified as chrysotile. Where such data are included in other reports, these values are typical. They are much greater than 110 nm apart, indicating a

¹³ McCrone, W., The Asbestos Particle Atlas. Ann Arbor Science Publishing Inc. Ann Arbor Michigan, 1980. To his data for λ_0 , I added the column showing the difference. In two locations identified by McCrone as Rhodesian and Italian; Balengera, a second set of λ_0 's is given suggesting a second period of crystallization under somewhat different conditions. There are no ranges given, however, so the chrysotile from these two locations has optical properties of one or the other with none in between.

birefringence (as determined in this way) that is too high for chrysotile and inconsistent with the ISO 22262-1.

Figure 19. Representative MAS data sheets for PLM analysis

MATERIALS ANALYTICAL SERVICES, LLC PLM ANALYSIS			
Proj#-Spl#	M70859-001CSMP	Analyst Paul Hess	Date 5/25/2021
ClientName	Phillips & Paolicelli, LLP	ClientSpl	01
Location			
Type_Mat	Talc (pellet from CSM)		
Gross	Light gray debris on filter	% of Sample	100
Visual		Temp (±1°C)	21
OPTICAL DATA FOR ASBESTOS IDENTIFICATION			
Morphology	wavy		
Pleochroism	none		
Refract Index	**		
α / γ (nm)	620 450		
Sign^	positive		
Extinction	parallel		
Birefringence	*		
Melt	no		
Fiber Name	Chrysotile		
ASBESTOS MINERALS		EST. VOL. %	
Chrysotile.....		0.020 to 0.022	
Amosite.....			
Crocidolite.....			
Tremolite/Actinolite.....			
Anthophyllite.....			

**MATERIALS ANALYTICAL SERVICES, LLC
PLM ANALYSIS**

Proj#-Spl# M71211- 007CSMP Analyst Paul Hess Date 5/14/2021
ClientName Weitz & Luxenberg PC ClientSpl 20200342-07
Location Date code on Original Container: 0680ZA3 00:55
Type_Mat Johnson's baby powder
Gross debris on filter % of Sample 100
Visual _____ Temp (±1°C) 21

OPTICAL DATA FOR ASBESTOS IDENTIFICATION

Morphology	wavy		
Pleochroism	none		
Refract Index	**		
α / γ (nm)	640	450	
Sign^	positive		
Extinction	parallel		
Birefringence	*		
Melt	no		
Fiber Name	Chrysotile		

ASBESTOS MINERALS**EST. VOL. %**

Chrysotile.....	0.010 to 0.013
Amosite.....	
Crocidolite.....	
Tremolite/Actinolite.....	
Anthophyllite.....	

OTHER FIBROUS COMPONENTS

NON FIBROUS COMPONENTS

Talc	X
Mineral grains	X

Comments Chrysotile asbestos observed. ** Refractive indices parallel were 1.559(513nm) to 1.568(450nm). Refractive indices perpendicular range 1.548(640nm) to 1.554(570nm). *Birefringence from low to moderate. X=Materials Detected. 35 Chrysotile structures, inclusive of those documented by photograph, counted in 30 fields of view. Equates to 1.5 structures per square millimeter.

The method detection limit is 1% unless otherwise stated.

In two reports, M71262 and M70859, the values of λ_0 parallel and perpendicular were determined by MAS for many samples; these data are compiled in **Figure 20**. There are two observations that can be made from these data.

First, λ_0 parallel is lower than almost all of the chrysotile λ_0 from McCrone and λ_0 perpendicular to elongation is higher. The difference between the two is in all cases greater than 130 nm, indicating a birefringence higher than that of all other reported chrysotile.

Second, the values given by MAS for λ_0 parallel to elongation are outside the range known for chrysotile as shown in **Figure 17** but instead fall within the range expected for talc.

Taken together, these two observations demonstrate that all particles identified in these two samples are talc, not chrysotile.

Figure 20. λ_0 perpendicular and parallel to elongation from the Optical Data sheets in MAS Reports M70859 and M71262 and working temperature in degrees centigrade. Both samples were examined in Series E 1.550 immersion oils.

	Sample	λ_0 Perpendicular (nm)	λ_0 Parallel (nm)	T
a. M70859				
	001CSMP	620	450	21
	002CSMP	600	455	21
	003 CSMP	850*	455	21
	004 ISO	620	455	21
	005 CSMP	590	445	21
	006 CSMP	640	455	21
	007 CSMP	600	450	21
	008CSMP	640	455	21
	009CSMP	600	455	21
b. M71262				
	001ISO	595	450	22
	001CSM	595	450	20
	002ISO	610	450	22
	002CSM	610	450	20
	003 ISO	630	470	22
	003CSM	630	470	20
	004 ISO	650	450	21
	004 CSM	630	450	20
	005ISO	640	460	21
	005CSM	600	450	21
	006ISO	620	450	21
	006CSM	750	460	21

λ_0 between 590 and 650 will appear blue to blue green and λ_0 between 445 and 470 will appear yellow to golden yellow. These are the two most common colors shown in the dispersion staining photographs of the minerals identified as chrysotile by MAS in all reports.

G. Coalinga (Calidria)

Coalinga chrysotile does not have optical properties consistent with those of the particles MAS identifies as chrysotile.

I have examined the Coalinga chrysotile, which in its report on this material MAS asserts is like the chrysotile it finds in Johnson & Johnson talc products. The Coalinga chrysotile product is a mineralogically complex material and contains minerals other than chrysotile as shown in **Figure 21**. The optical data MAS has presented for the Coalinga chrysotile is not for chrysotile at all, but rather one of the other minerals present, such as pyroaurite and/or brucite. This misidentification is likely due to both a misinterpretation of dispersion staining colors and ignoring other defining characteristics that could be determined by a comprehensive mineralogical examination, considering all factors described under Section A of this report. Furthermore, Coalinga chrysotile stains blue and blue magenta in 1.550 Series E oils, a fact seemingly overlooked by MAS.

Figure 21. Minerals known from Coalinga (Calidria)¹⁴

Mg Silicates, hydrates, and carbonates. Optical properties

The range in gamma and alpha Longo has matched to chrysotile from Calidria are: Gamma (1.57-1.55) and alpha (1.56-1.54). According to his logic, as long as N and n each fall somewhere within their respective range, he was satisfied with his identification. The following minerals may occur with chrysotile in Calidria materials:

Antigorite $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ alpha is 1.56-1.57 and gamma is 1.56 and 1.58.

Lizardite. $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$. Alpha is 1.54 to 1.56 and gamma is 1.55 to .57

Pyroaurite $\text{MgCO}_{3.5}\text{Mg}(\text{OH})_{22}\text{Fe}(\text{OH})_3 \cdot 4\text{H}_2\text{O}$ uniaxial negative $\omega = 1.564$ $\varepsilon = 1.543$ (fragments length slow)

Sjogrenite $\text{MgCO}_{3.5}\text{Mg}(\text{OH})_{22}\text{Fe}(\text{OH})_3 \cdot 4\text{H}_2\text{O}$ uniaxial negative $\omega = 1.573$ and $\varepsilon = 1.559$ (fragments length slow)

Sepiolite- $\text{Mg}_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$ alpha from 1.498-1.522 and gamma 1.527-1.579. fibrous.

Stevensite $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ alpha = 1.500-1.560 and gamma = 1.510 to 1.570 depending on compositional substitutions for Mg. Brucite ($\text{Mg}(\text{OH})_2$) uniaxial positive with $\varepsilon = 1.580$ and $\omega = 1.560$. (Fibers length slow; fragments length fast)

¹⁴ Mumpton, FA and Thompson CS, Mineralogy and origin of the Coalinga asbestos deposit. In Clays and Clay minerals 23:131-143. 1975.

H. Temperature corrections lacking.

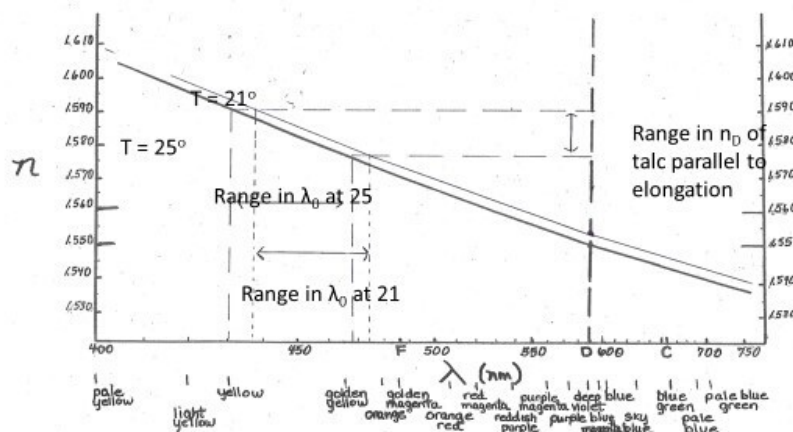
Changes in temperature affect dispersion staining colors but there is no evidence that MAS considered this error.

In many reports, especially the earlier ones, no laboratory temperature at the time of observation is recorded. Without consideration of temperature, a significant error in the determination of the index of refraction can result because of changes in the dispersion staining colors. **Figure 19** shows the MAS laboratory data sheets, in which a temperature of 21 degrees is recorded. In **Figure 22**, the impact of temperature is illustrated.

Low temperatures cause the oils to thicken and thereby increase their index of refraction. On every bottle of immersion oil, Cargille provides an estimate of how much. For 1.550 Series E, it can increase 0.0005 for every degree change below 25 C, the standard reference temperature. At a four-degree decrease (25-21), the indices of refraction of the oil 1.550 will actually be 1.552. In my own laboratory, we kept a thermocouple to measure temperature right in the oil mount when we wanted high precision in the measurement of the indices of refraction. Changing temperatures has no impact on the indices of refraction of minerals.

Figure 22. The effect of temperature on the index of refraction of immersion oils.

How does cold affect dispersion staining colors? λ_0 shifts to the right. Without correction, an error is introduced in n_D such that n_D derived from dispersion staining is low.



If λ_0 were determined at 21 degrees but no corrections were applied and the dispersion staining colors were interpreted for 25 C, a derived value of 1.585 would actually correspond to a value of 1.583 because λ_0 shifts to the right. For a mineral with higher dispersion, the shift of λ_0 would be greater and the error introduced higher. As the dispersion of the mineral increases, the error introduced increases.

Differences in index of refraction of this magnitude are meaningful differences in the world of mineralogy. By careful work, the index of refraction can be measured to a precision of ± 0.0005 , so an error of 0.002 is very large. Measurement and correction for temperature is standard

procedure in optical mineralogy, yet there is no indication if or how temperature corrections were made in the MAS reports.

I. Morphology of Asbestos

The particles identified by MAS do not have the morphology of chrysotile asbestos.

EPA method 600¹⁵ and ISO 22262-1 both provide criteria for the recognition of the habit of asbestos as observed by optical microscopy. They include a high aspect ratio (length/width) with a mean of about 20:1 and the presence of bundles that show evidence of splitting into very thin fibrils. The morphological properties of particles that have been identified by MAS as chrysotile are not characteristic of the properties of asbestos as described in these documents and or from my own experience. Because of the small chrysotile fibril width, usually $< 0.030 \mu\text{m}$, every particle identified as chrysotile would have to have be a bundle because individual fibrils cannot be seen by optical microscopy. Most of the particles MAS calls chrysotile could not be described as fibrous at all. The pattern of interference colors produced when the mineral particle is in the 45-degree position and both the polarizer and the analyzer are in the optical path, displays distinctive properties if the particle is a bundle of fibrils; such properties were not characteristic of the particles identified as chrysotile. Fiber bundles give distinctive interference figures, but there is no evidence that interference figures were observed, despite the fact observation of interference figures is always recommended for identification of birefringent minerals by polarized light.

J. Relief and Becke lines

Relief of particles identified as chrysotile is consistent with talc and inconsistent with chrysotile.

Relief is a qualitative term that describes the depth of shadows of the mineral grain when it is observed under the microscope without the dispersion staining objective or the analyzer in the optical path. For every particle that MAS provides a picture of the dispersion staining colors, a picture of the grain that demonstrates relief is also provided. **Figure 24** from Bloss provides an illustration of how relief is described. It can be low, medium, high, or very high. The relief changes as the difference between the mineral grain and the oil change, with maximum relief observed when the differences are very high and low relief when the differences in indices of refraction are small.

Figure 25 is an example taken from an MAS report. Other examples are provided in Appendix 3. The indicated particle is supposed to be chrysotile, while the other particles are talc. The colored fringes around the particles are Becke lines, another indication of the differences in indices of refraction between the mineral particles and the immersion oil in which they are mounted. In both relief and in the color of the Becke lines, the indicated particle cannot be distinguished from the talc particles. Were it actually chrysotile, this would not be the case.

¹⁵ Perkins RL and Harvey BW, Test Method: Method for the determination of asbestos in bulk building materials. USEPA/600/R-93/116, 1993.

Relief and Becke lines of talc will vary with orientation and for that reason relief and Becke lines will vary somewhat. This is not the case for chrysotile, for which indices of refraction are not affected by orientation.

Figure 24. Relief of mineral grains vary.

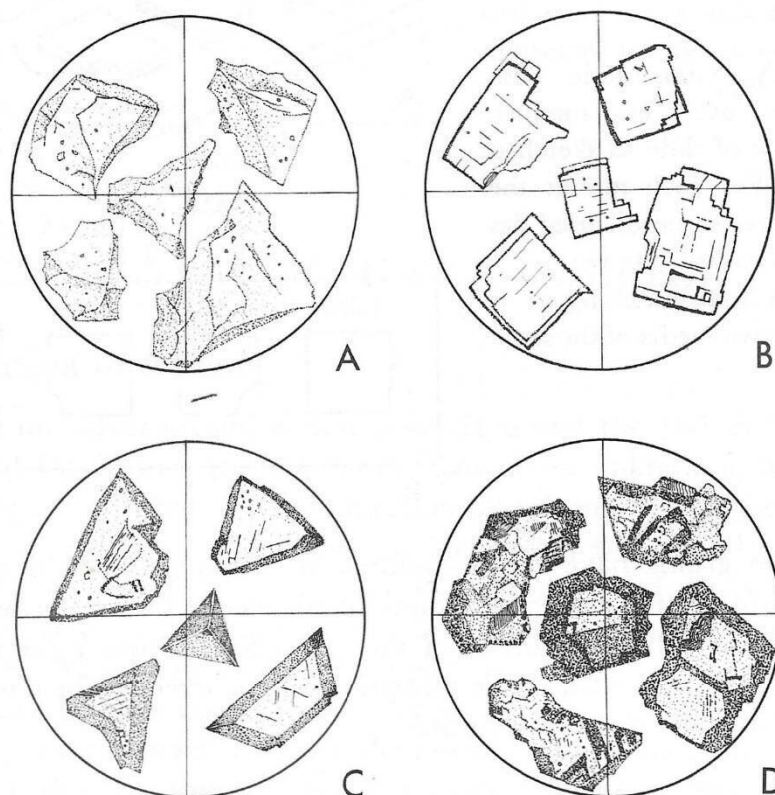


Fig. 5-12. Breakage types commonly seen on crushed isotropic grains: (A) conchoidal fracture but no cleavage; (B) cubic cleavage $\{100\}$ —that is, three mutually perpendicular directions of equal ease of cleavage; (C) octahedral cleavage $\{111\}$ —that is, four directions of equal ease of cleavage that are parallel to the faces of an octahedron; (D) dodecahedral cleavage $\{110\}$ —that is, six directions of equal ease of cleavage parallel to the faces of the dodecahedron. Note that for dodecahedral cleavage the fact of six “competing” directions for cleavage makes it unlikely that a particular direction will be extensively developed; instead, the breakage surface alternately follows one and then another of these six directions. The relief of these grains in oil varies as follows: (A) low, (B) moderate, (C) high, (D) very high.

Figure 25. Typical photomicrograph illustrating relief. MAS has called the designated particle chrysotile. Note the similarity in relief and Becke lines to the particle on its right.



K. Other issues

ISO 22262-1 Method specifies that samples should be heated to 485 degrees C before examination. We know that chrysotile is stable at these high temperatures, but they are high enough to remove organic fiber that may have contaminated talc powders. Some of these organic fibers can be confused with chrysotile. In the reports, MAS says it heated the samples but the temperatures given are variable, and include 400C, 425C, 480C, and 400F. It is not clear why MAS does not follow the recommendations of the ISO method.

In MAS Supplemental Report 07.31.23, MAS describes milling a NIST chrysotile standard to more closely resemble the particle sizes of talcum powder. MAS seems to believe that size reduction changes the indices of refraction.

“MAS has recently completed a study where the NIST chrysotile standard was milled with liquid nitrogen ball mill to reduce the size of chrysotile bundles to a 200 sieve. The talc particle size standard for cosmetic talc is a -200 sieve. Our results showed that when the 1866b chrysotile bundles were reduced in length and thickness that was consistent with both the SG-210 and the cosmetic talc chrysotile bundles, the CSDS (central stop dispersion staining) colors are consistent with both the SG-210 and cosmetic talc chrysotile.”

Unless size reduction alters the atomic structure of the material, which is unlikely if grinding is done under liquid nitrogen as described, indices of refraction and associated dispersion staining colors will not change. Index of refraction is dependent on the atomic structure and chemical composition, neither of which is normally altered by size reduction. Ball milling can be destructive to the atomic structure of minerals if it persists for many hours, but details of this “study” are not provided.

In that same Supplemental Report 07.31.23, MAS states that the difference in observing talc powder in Series E 1.560 vs 1.550 is that the

“measured refractive indices for the 1.560 RI Fluid were closer together for the alpha and gamma directions, which caused the BIR calculations to be all in LOW range with an overall average of 0.006 versus 0.010-0.013 range typically seen using 1.550 RI fluid.”

This statement implies either that the indices of refraction and birefringence change depending on the immersion oil, which is not true, or it is a recognition that calculated birefringence MAS has tabulated from its 1.550 studies are incorrect.

Chrysotile fibrils are most readily identified by transmission electron microscopy (TEM). Their chemical composition in combination with their tubular morphology and small widths make identification by TEM very reliable. Why MAS did not use TEM to confirm the presence of chrysotile in all samples is not clear. Were I concerned about the presence of chrysotile, I would certainly use TEM and not light microscopy. Where MAS did use TEM, it did not report chrysotile, strong evidence that it is not present.

Summary

In conclusion, I do not see any evidence in the reviewed MAS reports that any chrysotile fibers were identified in the samples.

MAS does not consider the full range of optical properties that are standard and necessary to identify unknown minerals. Had they, it would have been clear that the mineral particles they identify as chrysotile are talc.

MAS misinterprets the dispersion staining colors of some elongate talc particles to produce values of the index of refraction parallel and perpendicular to elongation that are incorrect and inconsistent with the dispersion staining colors.

MAS relies on the incorrectly derived indices of refraction to determine an incorrect birefringence and does not consider other types of optical data that could be used to demonstrate this error.

The differences in λ_0 parallel and perpendicular to elongation are inconsistent with chrysotile and do not conform to the values specified for the identification of chrysotile by ISO 22262-1.

MAS assumes that the range in the dispersions staining colors observed from the particles they identify as chrysotile is due to chemical compositional variation in chrysotile. Chrysotile from different locations (with different physical and chemical conditions governing formation) may vary among occurrences, but available published data show that within a single occurrence, they do not occur with a range of values. The variation MAS reports in dispersion staining colors is due to variations in the orientation of talc particles.

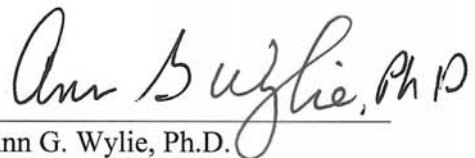
MAS does not correct for temperature which changes the index of refraction of the immersion oils used, introducing error and compromising an accurate determination of index of refraction.

MAS provides pictures of particle relief, but does not consider them. These pictures demonstrate that the relief of the particles indicated as chrysotile varies very little from talc particles and if there is a variation, it can be explained by orientation.

The particles identified by MAS do not have the optical or morphological characteristics of chrysotile fiber bundles.

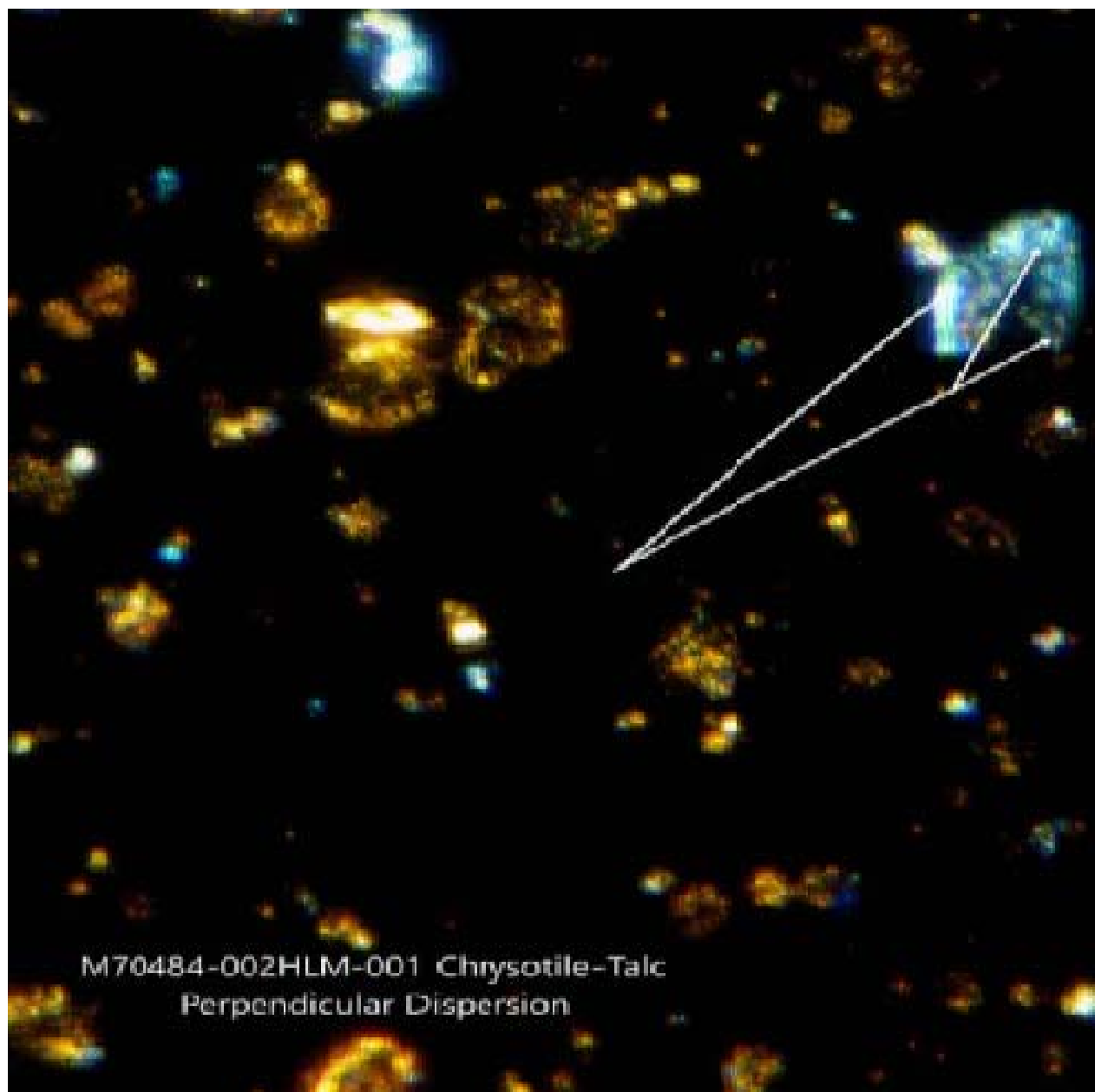
Other errors in the reports demonstrate inconsistent laboratory practices and misunderstanding of how optical properties can be affected by sample preparation for examination by PLM.

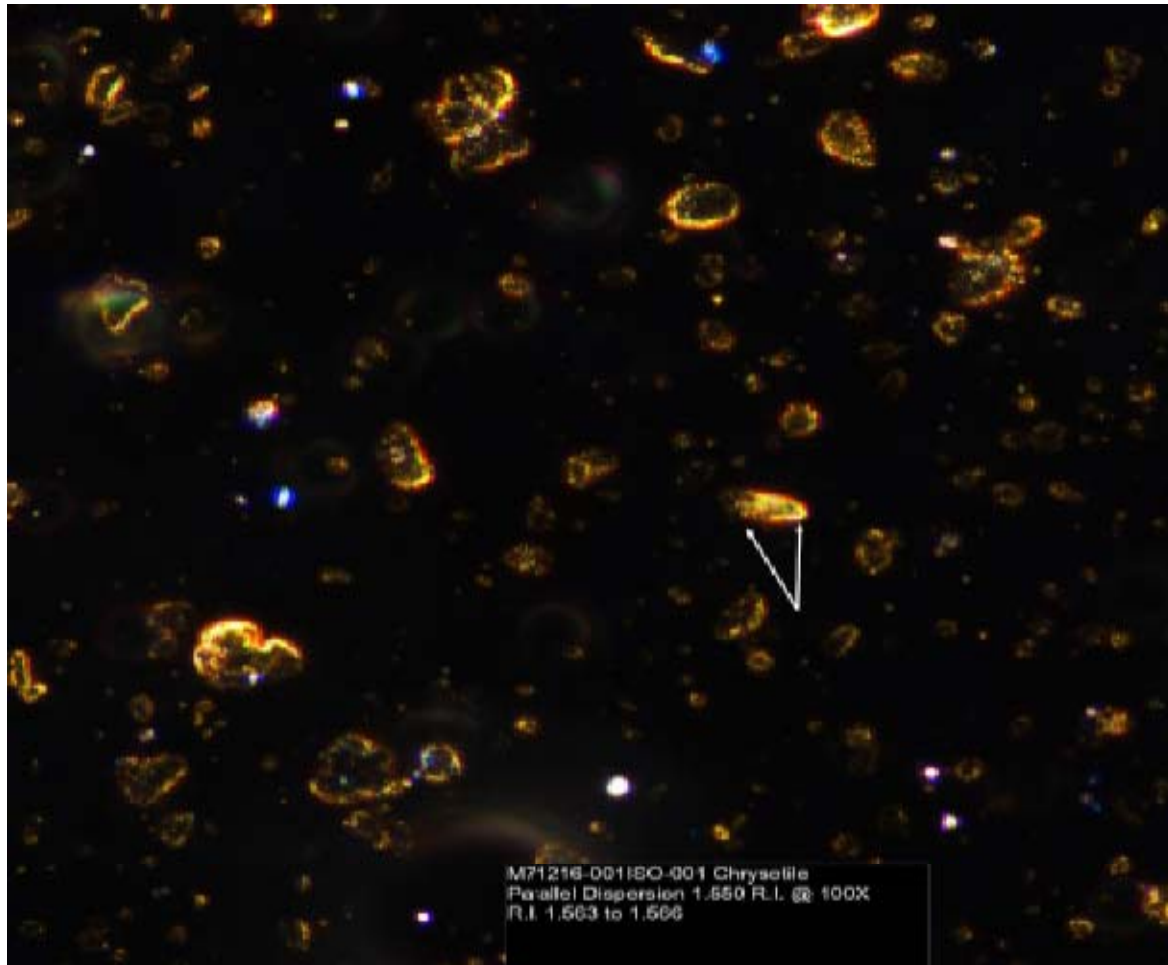
The lack of collaboration of the presence of chrysotile by TEM by a laboratory with TEM capabilities and experience is consistent with its absence.


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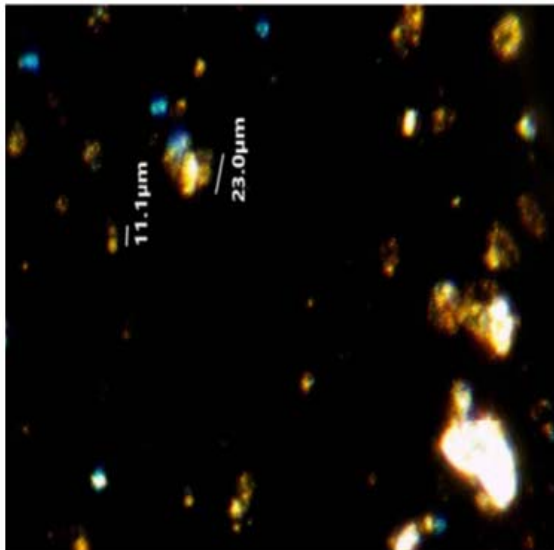
Appendix 1.

Additional examples of dispersion staining colors that are characteristic of talc but not chrysotile. Two orientations are shown: one with vibration direction of light parallel or near parallel to elongation (yellow) and perpendicular to elongation (blue). Note other particles not identified as chrysotile by MAS by arrows with the same dispersion staining colors. They are talc.

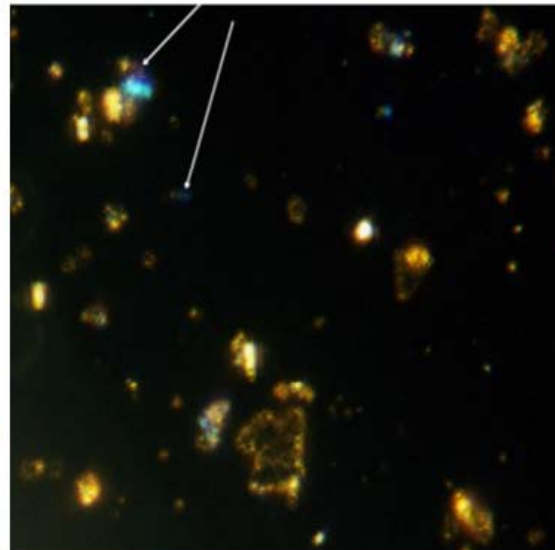


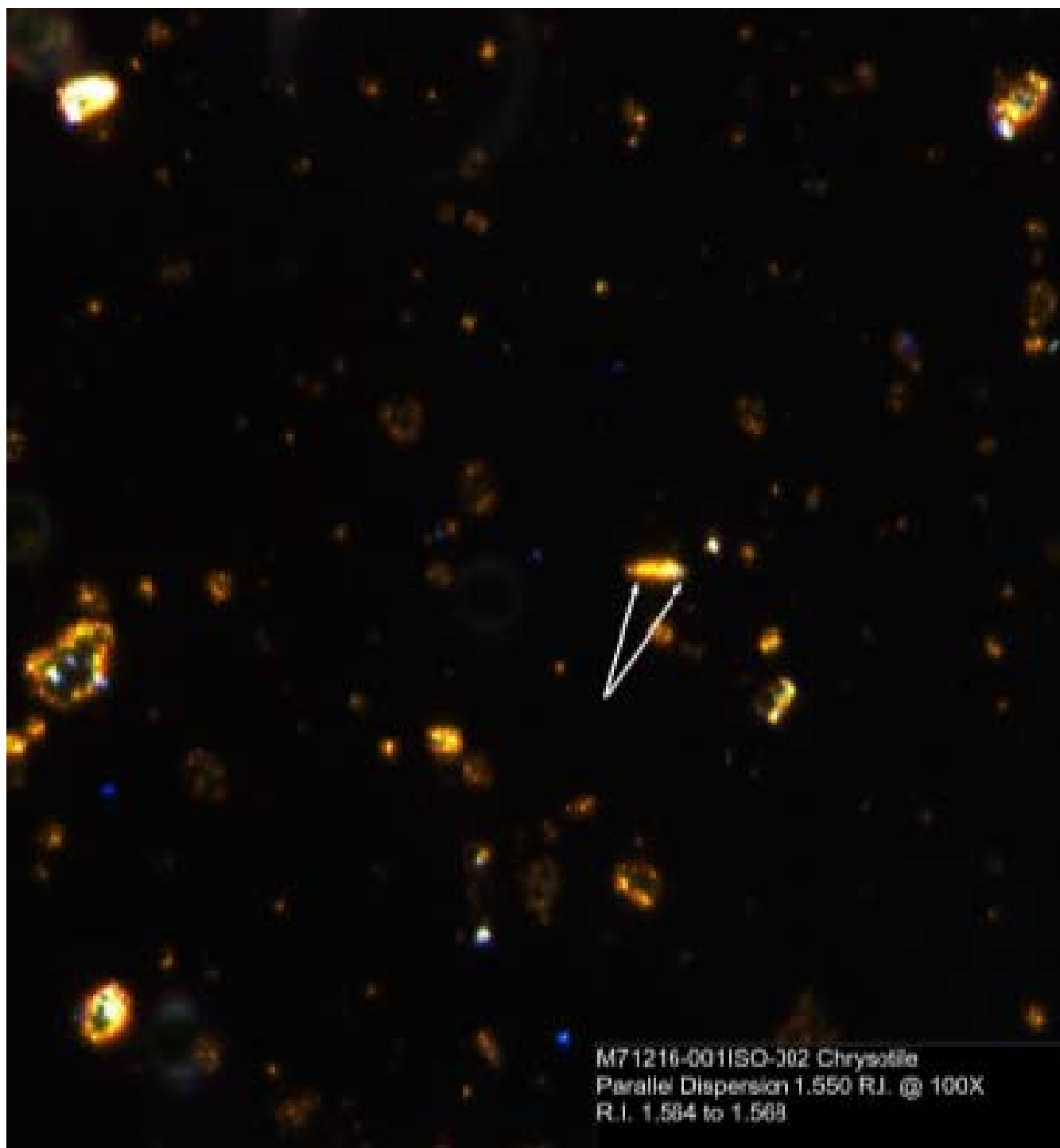


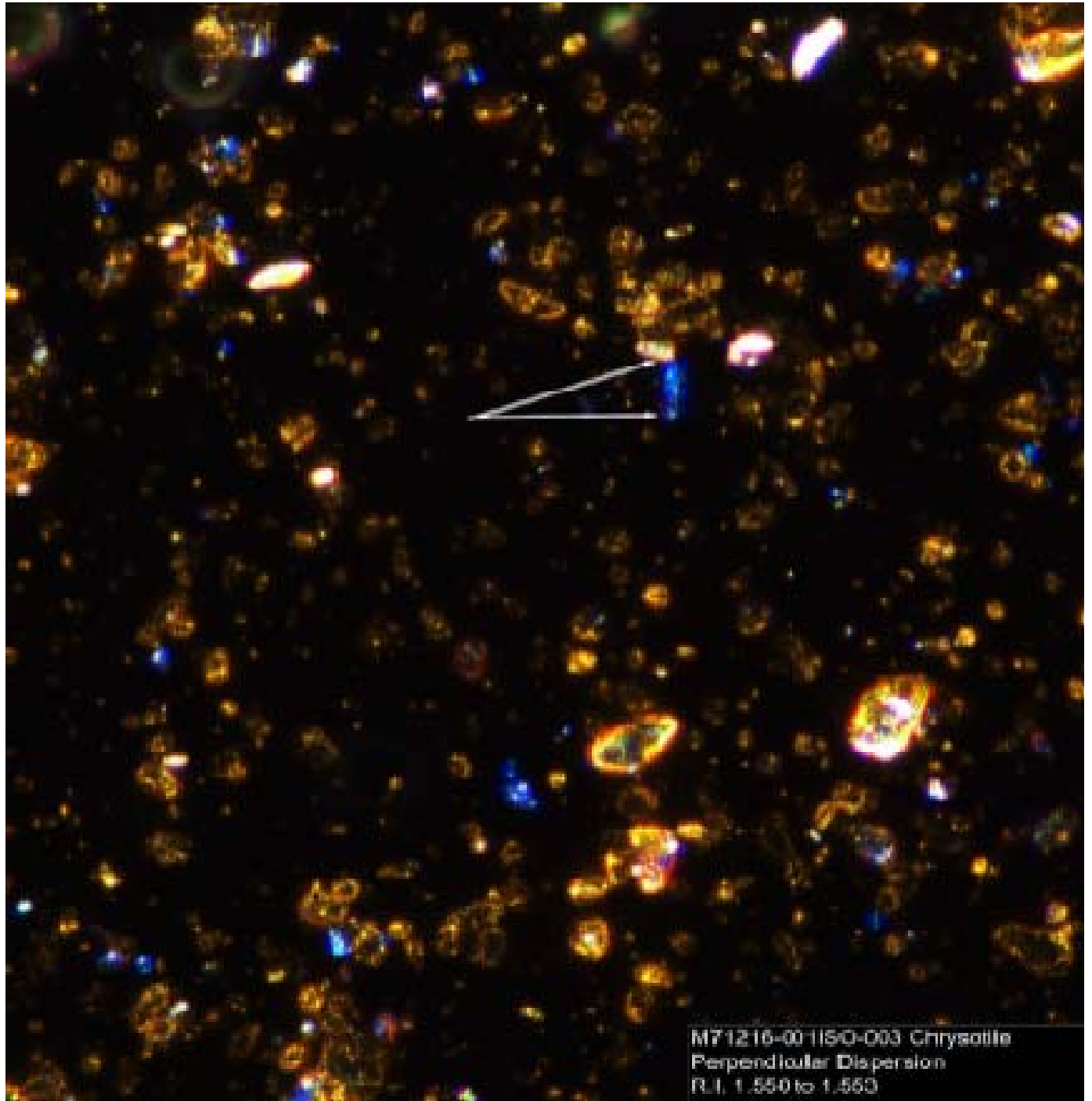
MAS70877.001CMS – 003 1.550 oil. Two particles identified as
chrysotile by MAS
parallel



perpendicular

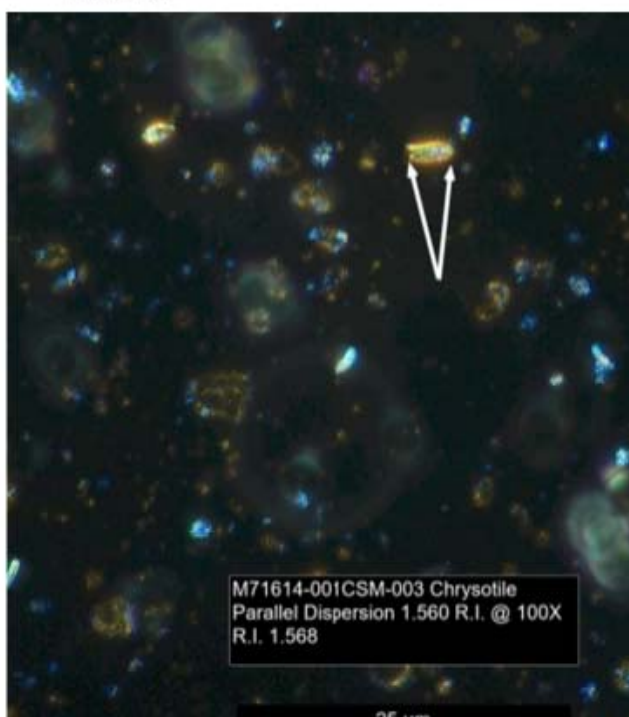




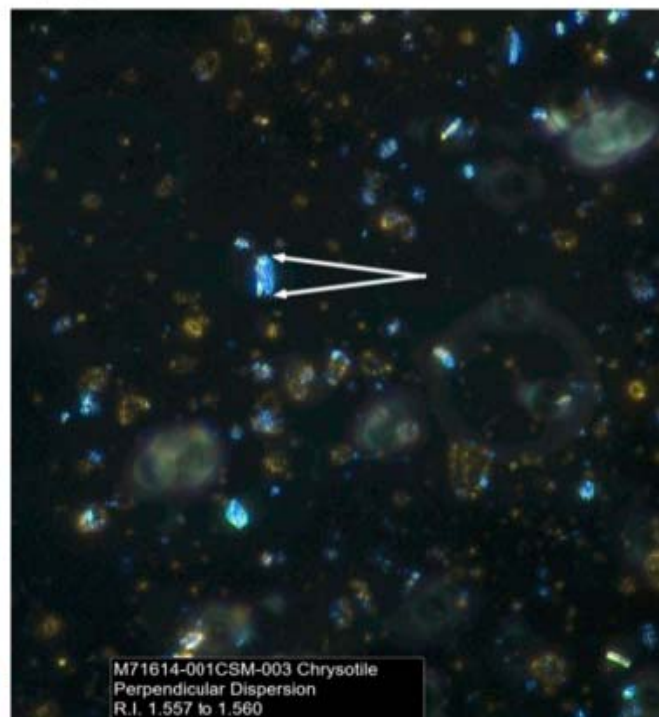


M71214-001CSM MAS specifies λ_0 parallel 510nm, λ_0 perpendicular 650 nm T=22 nD= 1.560

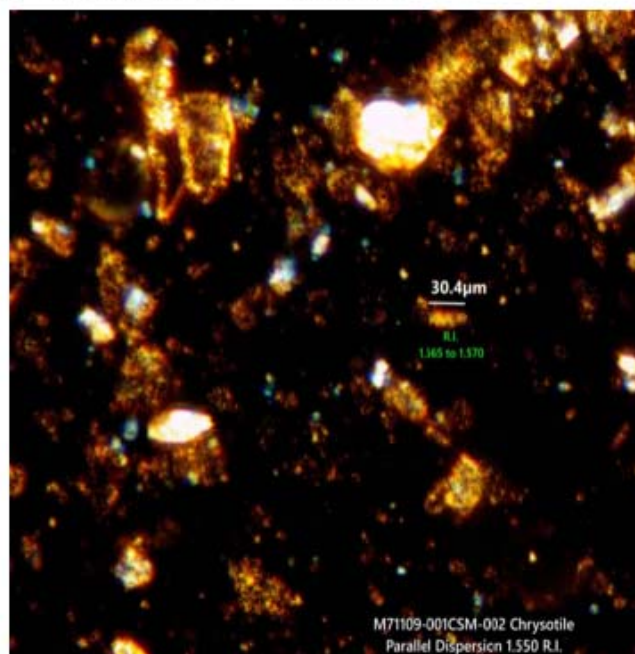
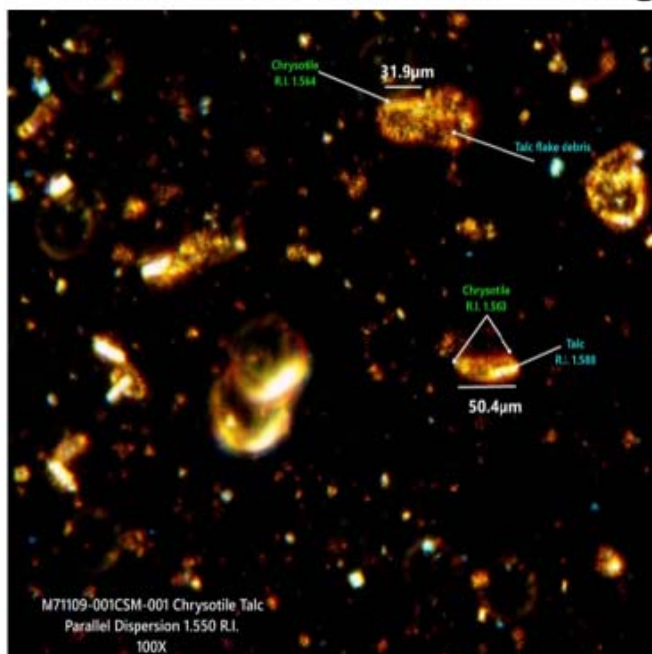
Parallel



perpendicular



MAS 71109 talc from Guangxi China nD = 1.550

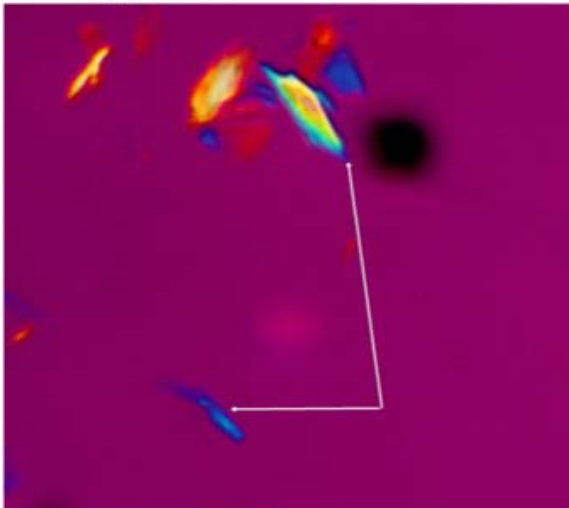


Appendix 2. Birefringence Calculations from observed retardation

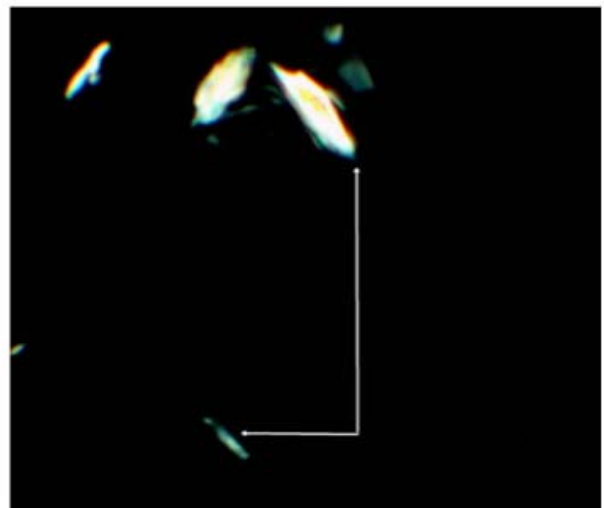
a. With red I compensator, interference colors for the larger particle is second order red (950nm). It is 23 μ m long and about 5 μ m wide. Using the Interference color chart and subtracting 550 nm for the Red I compensator gives a retardation of 400nm and a birefringence of about 0.05. This is too high for chrysotile but consistent with talc. The smaller particle has interference colors blue to green (700 nm) and subtracting 550nm gives a retardation of 150 nm. It is 11 μ m long so about 2 μ m in width. Although more difficult to pinpoint the birefringence from such a small particle, it is still on the order of 0.04.

MAS70877.001CMS – 003 1.550oil

23 μ in upper right, 11 μ in lower left Red I compensator

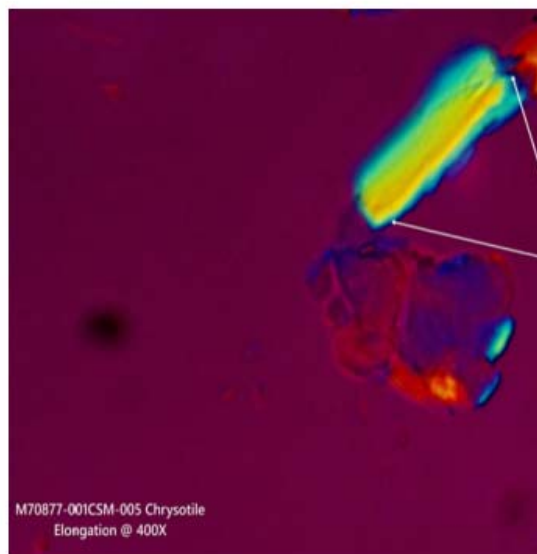
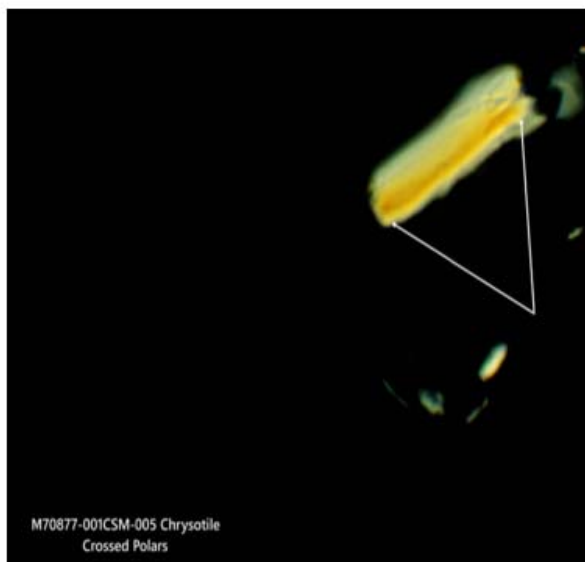


same particles without compensator.



- b. This particle is 45.2 μm long and about 10 μm in width. The figure on the left is without compensator and the figure on the right has the Red I compensator inserted. From the interference colors the retardation is about 400nm. This retardation corresponds to a birefringence of 0.040, too high for chrysotile but consistent with talc.

MAS70877 001CSM-005

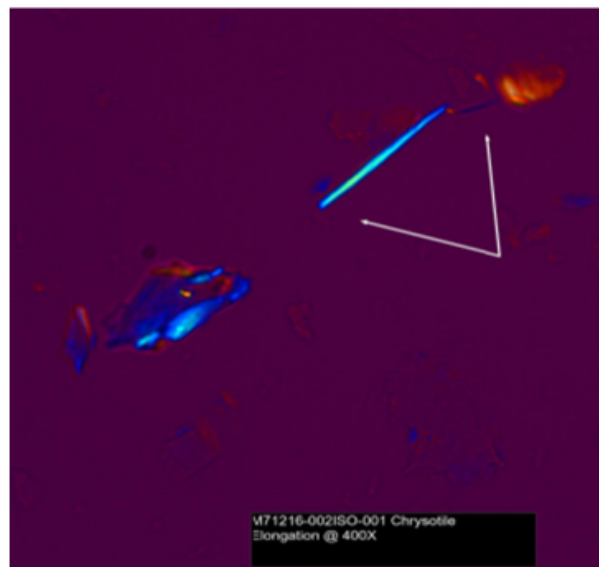
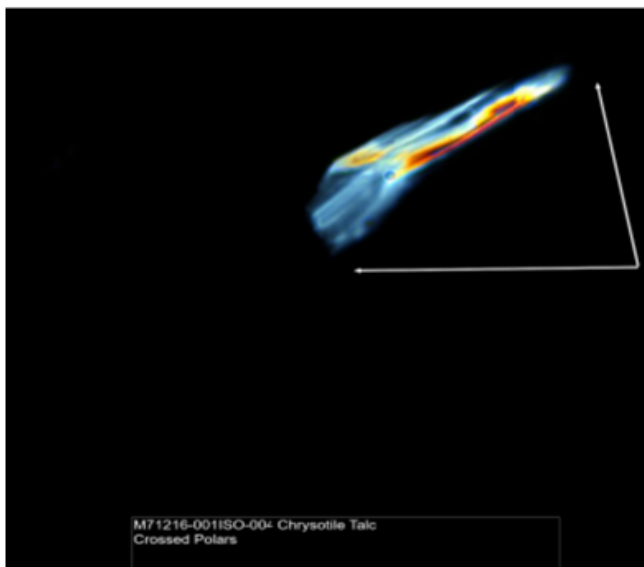


c.

Two examples from MAS M71216

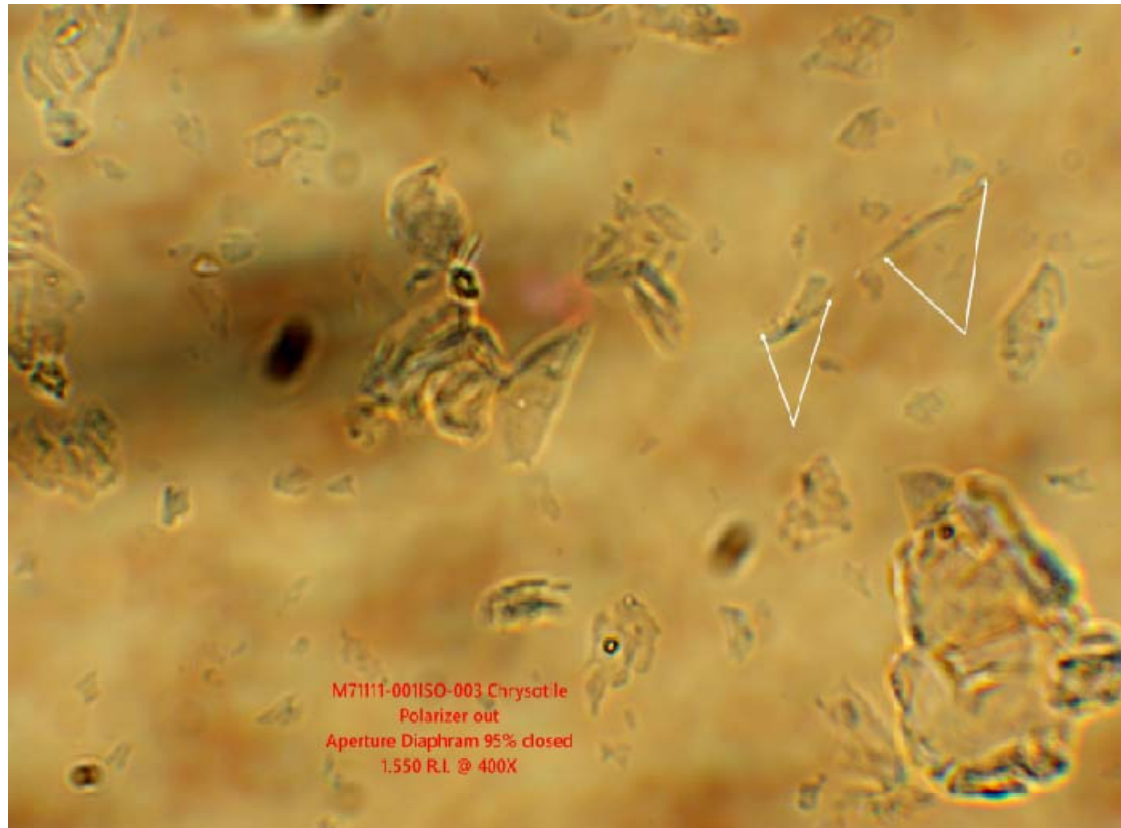
Retardation = 600nm Width \approx 12 μm
birefringence \approx 0.045

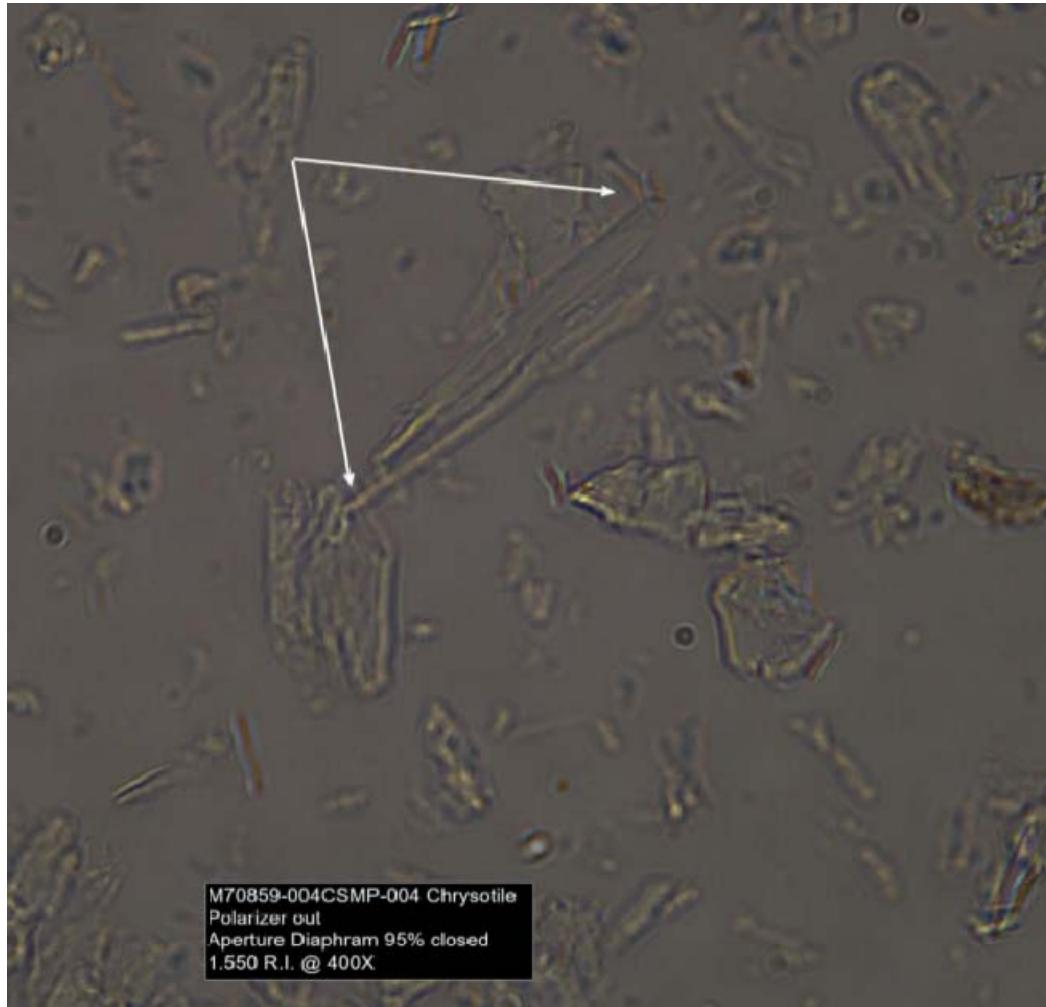
Retardation = 800-550 = 250 nm Width
 \approx 2 μm ; birefringence \approx 0.050



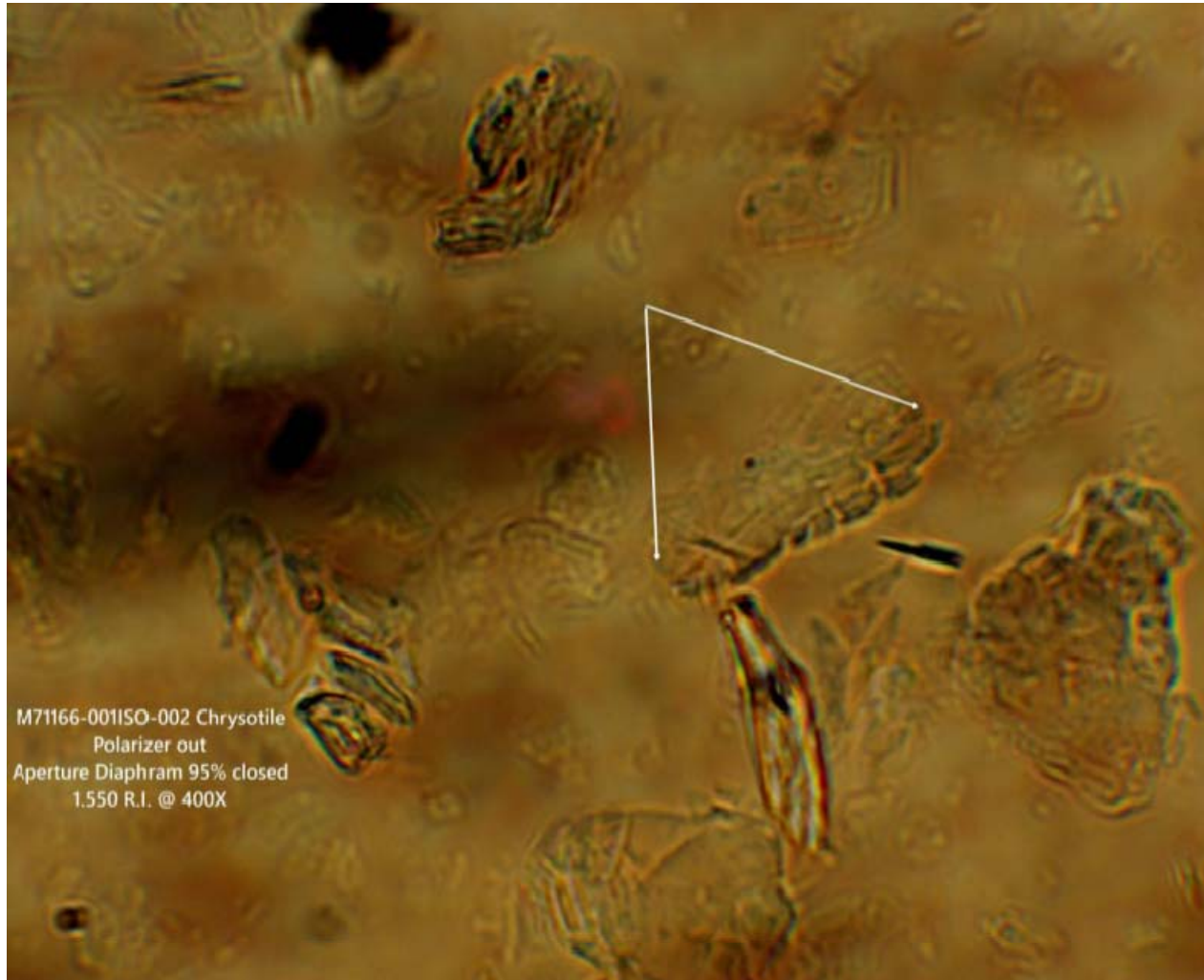
Appendix 3. Relief

The examples that follow show that the relief of the particles designated as chrysotile by the arrows have the same relief as the other particles in the photomicrograph which are talc.









Appendix 4

CURRICULUM VITAE

Ann G. Wylie

1. PERSONAL INFORMATION

Ann Gilbert Wylie
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Web site: <http://www.geol.umd.edu/pages/faculty/WYLIE/wylie.html>

Educational: Ph.D. 1972 Columbia University, New York, New York
Major: Economic Geology
Minors: Mineralogy, Mining Engineering, and Petrology

B.A. 1966 Wellesley College, Wellesley, Massachusetts
Major: Geology

Employment:

a. Academic:

2014 – Present	Professor Emerita, UMD
July 1 2021 – Aug 16 2021	Interim Vice President and Chief Financial Officer
Feb 2021 – June 30, 2021	Interim Senior Vice President and Provost, UMD
March 1, 2014 – June 30, 2014	Interim Vice President for Information Technology and Chief Information Officer, UMD
2012 – 2014	Special Advisor to the President for MPower, UMD
2012 – 2014	University Marshall, UMD
2011- 2012	Senior Vice President and Provost, UMD
2009- 2011	Vice President for Administrative Affairs, UMD

2008 – 2009	Interim Vice President for Administrative Affairs, UMD
2004-2006	Interim Dean of the Graduate School, UMD
2002-2008	Assistant President and Chief of Staff, UMD
2000-2002	Associate Provost, UMD
1998-2000	Acting Associate Dean, College of Computer, Mathematical and Physical Sciences, UMD
1996-1997	Undergraduate Director, Department of Geology, UMD
1992-2014	Professor, Department of Geology, UMD
1990-1994	Associate Chairman and Director of Graduate Studies, Geology Department, UMD
1989-1990	Acting Chairman, Geology Department, UMD
1986-1987	Special Assistant to the Dean for Graduate Studies and Research, UMD
1984-1986	Acting Associate Dean for Research, Graduate School, UMD
1977-1992	Associate Professor, Department of Geology, UMD
1973-1977	Assistant Professor, Department of Geology, UMD
1972-1973	Assistant Professor, Department of Agronomy, UMD
1967-1969 1970-1971	Preceptor, Geology Department, Columbia University
1966-1967	Teaching Assistant, Geology Department, Columbia University

b. Other Positions:

January 1981- August 1981	Mineralogist, U.S. Bureau of Mines,
February 1984- Present	Senior Scientific Advisor, Chemical and Industrial Hygiene

2. Research, Scholarly, and Creative Activities

a. Books

i. *Chapters or Articles in Books:*

Gilbert, J. Ann (1967) "Units, Numbers, Symbols and Constants", Encyclopedia of Atmospheric Sciences and Astrogeology, Rhodes Fairbridge (Ed.). Reinholt Publishing Company, p. 1049-1062.

Wylie, A.G. (1981) Numerous Mineral Descriptions in Encyclopedia of Mineralogy, K. Frye (Ed.). Reinholt Publishing Company.

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Veblen, D.R. and A.G. Wylie (1993) "Mineralogy of Amphiboles and 1:1 Layer Silicates" in Health Effects of Mineral Dusts, G.D. Guthrie & B.T. Mossman (Eds.). Reviews in Mineralogy, v. 28, Min. Soc. Am., p. 61-131.

Invited

Wylie, A.G. (1995) "The Analysis of Industrial Mineral Products for Crystalline Silica by Optical and Electron Microscopy: A Literature Review". In: Review Papers on Analytical Methods, Chemical Manufacturers Association.

Invited

Wylie, A.G. and P.A. Candela (1999) "Metallic Mineral Deposits - Chromite". In Geol. of Pennsylvania, Pennsylvania Geol. Survey and Pittsburgh Geol. Survey, Special Publication 1, p.588-595.

Invited

Wylie, A.G. (2017) Mineralogy of Asbestos and fibrous erionite. In *Current Cancer Research: Asbestos and Mesothelioma*, Joseph Testa Ed. Springer, Heidelberg 11-41.

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Wylie, AG (2024 in press) Mineralogical Characteristics and Risk assessment of elongate mineral particles (EMPs): Asbestos, fiber and fragment in Health Risk Assessment for Asbestos and other fibrous minerals, A A Korchevskiy, ed. John Wiley and Sons

b. Edited publications

Weill P, Chatfield E, Gibbs G, Wylie A, Eds. (2018). The Monticello Conference on elongated mineral particles, Journal of Toxicology and Applied Pharmacology 367:1-186.

b. Articles in Refereed Journals

Wylie, A.G. and P.J.M. Ypma (1974) "Determination of the Optical Parameters, n and k, of Absorbing Minerals with the Microscope: Isotropic Minerals". Economic Geology 52, p. 1300-1327.

Wylie, A.G. (1979) "Fiber Length and Aspect Ratio of Some Selected Asbestos Samples". Annals of the New York Academy of Science 330, p. 640-643.

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Zoltai, Tibor and A.G. Wylie (1979) "Definitions of Asbestos-related Mineralogical Terminology". Annals of the New York Academy of Science 330, p. 640-643.

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Siegrist, H.G. and A.G. Wylie (1980) "Characterizing and Discriminating the Shape of Asbestos Particles". Environmental Research 23, p. 348-361.

Campbell, W., C. Huggins and A.G. Wylie (1980) "Chemical and Physical Characterization of Amosite, Chrysotile, Crocidolite and non-fibrous Tremolite for Oral Ingestion Studies by NIEHS". Bureau of Mines Report of Investigation #8452, p. 1-63.

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Shedd, K.B., R.L. Virta and A.G. Wylie (1982) "Are Zeolites Dimensionally Equivalent to Asbestos?" In Process Mineralogy II: Applications in Metallurgy, Ceramics and Geology, R.D. Hagne (Ed.). Proceeding of Metallurgical Society of AIME, p. 395-399.

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Shedd, K.B., R.L. Virta and A.G. Wylie (1982) "Size and Shape Characterization of Fibrous Zeolites by Electron Microscopy". Bureau of Mines Report of Investigation #8674, p. 1-20.

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Wylie, A.G., R. Virta and E. Russek (1985) "Characterizing and Discriminating Airborne Amphibole Cleavage Fragments and Amosite Fibers: Implications for the NIOSH Method", American Industrial Hygiene Association Journal 46, p. 197-201.

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Wylie, A.G. (1988) "Relationship between the Growth Habit of Asbestos and the Dimensions of Asbestos Fibers". Mining Engineering, November (1988) p. 1036-1040.

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Wylie, A.G. (1993) "Modeling Asbestos Populations: The Fractal Approach". Canadian Mineralogist 30, p. 437-446.

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Carcinogenicity and its Implications for Public Policy". American Industrial Hygiene Association Journal 54, p. 239-252.

Wolven-Garrett, A., R.J. Wulf, A.G. Wylie, EL Wynder, J Yourik, B Sakarian, W. Zavadoski, R. Zaaenshi (1995) Talc: Consumer uses and health perspectives: Executive Summary. Regulatory Toxicology and Pharmacology v.21 #2 213-215.

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amphibole and serpentine in ambient air and water. Journal of Toxicology and Environmental Health, Part B: Critical Reviews. 18: 1-42.

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Wylie AG, Korchevskiy AA, Segrave A, and Duane A (2020) Modeling mesothelioma risk factors from amphibole fiber dimensionality: mineralogical and epidemiological perspective. *Journal of Applied Toxicology*, 2010:1-10 DOI: 10.1002/jat.3923

Korchevskiy, AA. and AG. Wylie, (2021) Dimensional determinants for the carcinogenic potency of elongate amphibole particles. *Inhalation Toxicology* 33. No. 6-8p.244-259

Korchevskiy, AA. and AG. Wylie (2021) Letter to the Editor: Confirmation of carcinogenicity of fibrous glaucophane: How should we fill the data gaps? *Current Research in Toxicology*

Korchevskiy, AA and AG Wylie (2022) Dimensional characteristics of major mineral types of amphibole particles and implications for carcinogenic risk assessment. *Inhalation Toxicology*.

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Wylie, A.G., Korchevskiy, A. A., Van Orden, D. R. ,Chatfield, EJ, (2022) Discriminant analysis of asbestiform and non-asbestiform amphibole particles and its implications for toxicological studies, *Computational Toxicology* 2022 100233.

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Wylie, AG and Korchevskiy, AA, Darnton, L, Chatfield E, Peto J, Van Orden D, Garabrant, D (2023) Elongate mineral particles (EMP) characteristics and mesothelioma: summary and resolution for Session I of the Monticello II conference . *Environmental Research* 230 114754

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impact of elongate mineral particles. Environmental Research 115353

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DOI:<https://doi.org/10.1080/08958378.2023.2213720>

c. Book Reviews Other Articles, and Notes

Invited

Book review of Optical Mineralogy: Theory & Technique by E.G. Ehlers. In: American Scientist, Nov. /Dec. (1988).

Invited

Book review of Ultramafic Rocks of the Appalachian Piedmont, GSA Spec. Paper 231, Steven K. Mittweide and E.F. Stoddard (eds.), 103 pages, Economic Geology 85 (1990).

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d. Other Publications

Gilbert, Jean Ann (1972) Determination of the Index of Refraction and Coefficient of Absorption under the Microscope: A New Method and Some of Its Applications. Ph.D. Thesis, Columbia University.

Wylie, A.G., L. Johnson, R. Reichlin, E. Steel, and R. Virta (1977). "Mineralogy and Size Distribution of Asbestos". University of Maryland Electron Microscope Central Facility. Newsletter #5.

Lowry, J. and A.G. Wylie (1979) "Mineralogy and Fiber Size Analysis of Amosite". University of Maryland, Electron Microscope Central Facility Newsletter #7.

Steel, E. and A.G. Wylie (1979) "Characteristics of the Asbestiform Habit". Society of Mining Engineers-American Institute of Mining Engineering Annual Meeting, Tucson. Preprint, p. 1-6.

Invited

Wylie, A.G., K.B. Shedd and M.E. Taylor (1982) "Volume Measurements of Asbestos in the SEM". University of Maryland Electron Microscope Central Facility, Newsletter #9.

Invited

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Invited

Wylie, A.G. (1989) "Mineralogical Definitions for Asbestos Fibers and Cleavage

Fragments". Report of the Committee on Geology and Public Policy GPP012. Geological Society of America, p. 2-4.

Invited

Wylie, A.G. (1996) "Factors Affecting Risk from Biologically Active Minerals", Proceedings, Mineral Dusts: Their Characterization and Toxicology, Washington, D.C. Society for Mining Metallurgy & Exploration, Littleton, Colorado, Sept. 19-20, 1996, p. 33-46.

Prestegaard, K., Wylie, A.G. and Piccoli, P.M. (1999) Characterization of Grout Samples at Winding Ridge." Power Plant Research Program, Maryland Department of Natural Resources.

Schwartz, C., A.G. Wylie, A. Davis, B. James (2000) "Investigation of the Expansive Behavior of Chromium Tailings: Final Report on Phase II Investigations".

Piccoli, P.M., DeHarde, A., Wylie, A.G., and Prestegaard, K. (2000) "Development of a Grout for the Kempton Mine: Characterization (XRD, Chemical Analyses, and SEM/EPMA Data) of Starting Materials. Power Plant Research Project Report, Maryland Department of Natural Resources.

Weill, D., Chatfield, E, Cox, T, Gamble, J, Gibbs, G., and Wylie, A. (2016) Letter to the Editor in reference to: Hwang et al. The Relationship Between Various Exposure Metrics for Elongate Mineral Particles (EMP) in the Taconite Mining and Processing Industry, Journal of Occupational and Environmental Health, Vol. 11, pp 613-624, Journal of Occupational and Environmental health 12:6 D86-D87. DOI: [10.1080/15459624.2015.1006639](https://doi.org/10.1080/15459624.2015.1006639)

Wylie, A.G., Virta R.L., Shedd, K.B., and Snyder, J.G., 2015, Size and shape characteristics of airborne amphibole asbestos and amphibole cleavage fragments: Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2HP87>

Wylie, A.G., Schweitzer, P., and Siegrist, H.G., 2015, Size and shape characteristics of amphibole cleavage fragments from milled riebeckite: Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2S98X>

Wylie, A.G., and Virta, R.L., 2015, Size and shape characteristics of mountain-leather actinolite: Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2WT68>

Wylie, A.G., and Virta, R.L., 2015, Size and shape characteristics of South African actinolite asbestos (ferro-actinolite): Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2S138>

Wylie, A.G., and Virta, R.L., 2016, Size and shape characteristics of Indian tremolite asbestos: Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2IH7S>

Wylie, A.G., and Virta, RL 2016, Size distribution measurements of amosite, crocidolite, chrysotile, and nonfibrous tremolite: Digital Repository at the University of Maryland, <http://dx.doi.org/10.13016/M2798Z>

Goodman, JE, Wylie, AG, Chatfield, EJ, Gibbs, GW ad Weill, D, Feb 5, 2021. Naturally Occurring Asbestos: A resource document for the Pennsylvania Mine-Permitting Process where NOA may be present. Prepared for the Pennsylvania Aggregates and Concrete Association and NSSGA.

Wylie, A, Andreozzi A, Bailey M, Bandli B, Case, B, Della Ventura G, Glossop L, Gualtieri A, Gunter M, Halterman D, Heaney P, Leocat E, Mossman B. (2022) A report of the IMA working Group on Asbestiform Minerals IMA Annual Meeting Lyon July 2022.

e. Abstracts and Professional Papers presented

Gilbert, Jean Ann and P.J. Ypma (1969) "The Use of an Electro-Optical Compensator for the Determination of the Optical Properties of Opaque Minerals Under the Microscope", GSA Annual Meeting, Atlantic City, New Jersey.

Siegrist, H.G. and A.G. Wylie (1979) "Characterizing and Discriminating the Shape of Asbestos Particles", GSA Annual Meeting San Diego, California.

Invited

Wylie, A.G. and P. Schweitzer (1980) "The Effects of Grinding on the Shape of Wollastonite Particles". Symposium on Electron Microscopy and X-ray Applications to Environmental and Occupational Health Analysis, Penn State.

Huggins, C., A.G. Wylie and W. Campbell (1980) "Preparation and Selected Properties of Amosite, Chrysotile, Crocidolite and Non-fibrous Tremolite for Use in NIEHS Oral Ingestion Studies". Symposium on Electron Microscopy and X-ray Applications, Penn State.

Rosemeier, R.G., M.E. Taylor and A.G. Wylie (1981) "Low Cost 210K Gain Transmission Electron Microscope Image (TEMI) Intensifier". Electron Microscopy Society of America, Annual Meeting, Atlanta.

Virta, R., K. Shedd, A.G. Wylie and J. Snyder (1981) "Size and Shape Characteristics of Amphibole Asbestos and Amphibole Cleavage Fragments Collected on Occupational Air Monitoring Filters". Proceedings of the International Symposium on Aerosols in the Mining and Industrial Work Environment, University of Minnesota USBM-NIOSH, Minneapolis, Minnesota.

Broadhurst, C.L., Candela, P.A., Wylie, A.G. and Burke, T.M. (1983) "A Geochemical Study of the Host Rocks of the Copper-Iron-Cobalt Ores of Sykesville, Maryland: An Ultramafite-Associated Deposit. Geol. Soc. Am. Natl. Meeting, November, (1983).

Burke, T.M., P.A. Candela, and A.G. Wylie (1985) "Evidence for Detrital Ultramafic

Bodies in the Eastern Piedmont of Maryland". Geol. Soc. of America Northeastern Section, March (1985).

Wylie, A.G., P.A. Candela and T.M. Burke (1985) "Genesis of High-zinc Chromite and Associated Cobalt Mineralized Blackwall in the Sykesville District, Maryland Piedmont". Geol. Soc. of Amer. National Meeting, November (1985).

Muller, P.D., Candela, P.A. and A.G. Wylie (1985) "Liberty Complex: Polygenetic Melange in the Central Maryland Piedmont". Geol. Soc. of Amer. National Meeting, November (1985).

Invited

Candela, P.A. and Wylie, A.G. (1987) "The Geology of Radon in the Maryland Piedmont: The Development of a Research Plan". Southwest Geol. Soc. Amer.

Candela, P.A., Wylie, Ann G. and Muller, P. (1987) "Ore Deposits as Tectonic Indicators in Melange Terrane". AGU.

Wylie, A.G., Candela, P.A. and Burke, T.M. (1987) The Genesis of Ultramafite-Associated Fe-Cu-Co-Zn-Ni Deposits of the Sykesville District, Maryland Piedmont". Southeast Geol. Soc. Amer.

Linder, D.E. and Wylie, A.G. (1988) "Zeolites from the Paleozoic Metavolcanic James Run Formation, Piedmont Province, MD" Southeast Geol. Soc. Amer.

Invited

Wylie, A.G. "Discriminating Amphibole Cleavage Fragments from Asbestos: Rationale and Methodology. Abstracts of Communication. VII International Pneumoconiosis Conference, Aug. 23-26, 1988. Pittsburgh, NIOSH-ILD-BOM-MSHA-OSHA, p. 124.

Invited

Wylie, A.G. (1989) "Distinguishing Tremolite-Asbestos from Tremolite Cleavage Fragments on a Light Optical and Morphological Basis", VII International Pneumoconiosis Conference Proceeding of Workshop: Hazard Recognition of Mineral Dust. Pittsburgh, NIOSH-ILD-BOM-MSHA-OSHA.

Invited

Wylie, A.G., (1989) Fiber Mineralogy and Identification. Society of Mining Engineers Annual meeting

Wylie, A.G., Linder, D. and Candela, P. (1990) "Sedimentary Features of Appalachian Serpentinites". Geol. Soc. of Amer. National Meeting, Nov. (1990), p. A230.

Invited

Skinner, C. and Wylie, A. (1990) "Fibrous Tremolites". Bloss Symposium, VPI, Blacksburg, Virginia.

Invited

Wylie, A.G. (1992) The Analysis of Industrial Mineral Products for Crystalline Silica by Optical and Electron Microscopy. The Measurement of Crystalline Silica International Symposium, August (1992).

Wylie, A.G. (1993) The Fractal Distribution of the Mass of Asbestos Fiber and its Application to the Analysis of Industrial Minerals. Geological Society of America Annual Meeting, Boston.

Verkouteren, J.R. and Wylie, A.G. (1994) "Anthophyllite, Tremolite, and Actinolite Asbestos: Reference Materials and Optical Properties" Inter/Micro 94, Chicago.

Verkouteren, J.R., Wylie, A.G., Steel, E.B., Lim, M.S. (1995) "Analysis of the Tremolite-Actinolite Series using High Precision Refractive Index Measurements". Microbeam Analysis.

Invited

Wylie, A.G. (1996) Factors Affecting Risk from Biologically Active Minerals. Proceedings Society of Mining, Metallurgy & Exploration Symposium. Mineral Dusts: Their Characterizations and Toxicology. Washington DC 33-46

Invited

Wylie, A.G. (1997) "The Habit of Asbestiform Amphiboles: Implications for the Analysis of Bulk Samples" 1997 Boulder Conference: Advances in Environmental Measurement Method for Asbestos. University of Colorado, Boulder, July 13-17 (1997).

Verkouteren, J.R. and A. G. Wylie (2001) "Microdiffraction Analysis of Fibrous Talc: Asbestos in Crayons". 2001 Denver X-ray Conference, Steamboat Springs, Colorado, USA, August 2, 2001.

Piccoli, P.M., DeHarde, A., Wylie, A.G. (2001) "Recycling coal Combustion Byproducts: a Laboratory Study to Evaluate Grout Formulations for Use in the Kempton Mine Complex, Western Maryland. Geological Society of America, Abstracts with Programs.

Verkouteren, J.R. and A.G. Wylie (2001) "Identification of Tremolite-Actinolite Asbestos". 2001 Asbestos Health Effects Conference, May 24-25, 2001, Oakland, CA.

Verkouteren, J.R., A. G. Wylie, E. Windsor, J. Courny, R. Perkins, T. Ennis (2002) "Powder X-Ray Diffraction for Asbestos Analysis". International Centre for Diffraction Data. Annual Meeting of Members, ICDD Headquarters, Newtown Square, PA, March 20, (2002).

Greenwood, W. and A.G. Wylie (2002) "The Optical Properties and Chemical Composition of Fibrous Talc". ASTM Johnson Conference, July 21-25, Johnson, Vermont.

Verkouteren, J.R., and A.G. Wylie (2002) "A PLM Method for Quantitative Analysis of

Amphibole Asbestos in Bulk Materials at 0.01 wt. %". ASTM Johnson Conference, July 21-25, Johnson, Vermont.

Verkouteren, J.R. and A.G. Wylie (2002) "Optical Characteristics and Mineralogy of Environmental Amphibole Asbestos", ASTM Johnson Conference, July 21-25, Johnson, Vermont.

Verkouteren, JR and A G Wylie "Micro-diffraction Analysis of Fibrous Talc: Asbestos in Crayons. Denver x-ray conference.

Crummett, C.D., Candela, P.A., Wylie, A. G., and Earnest, D.J. (2004) "Examination of the Thermal Transformation of Chrysotile by Using Dispersion Staining and Conventional X-ray Diffraction Techniques". AGU Fall Meeting, V41C-1405.

Earnest, D. J., Candela, P.A., Wylie, A. G., Crummett, C. D, Frank, M. (2004) "Synchrotron Radiation Study of the Kinetics of Dehydration of Chrysotile Fiber". AGU Fall Meeting, V23C-06.

Frank, MR, Candela, PA, Earnest, DJ and Wylie, AG, Wilmot, M, Maglio SJ (2005) Experimental Study of the Thermal Decomposition of Lizardite up to 973 K, GSA Annual Meeting

Kerrigan, RJ, Candela, PA, Piccoli, PM, and Wylie, AG, (2007), Growth of Fibrous Talc and Anthophyllite in the Hydrothermal Diamond Anvil Cell (HDAC), American Geophysical Union Fall Meeting, December 10-14, 2007, San Francisco.

Taylor, ES, Lower, SK, Wylie, AG, and Mossman, BT: The strength of disease: molecular bonds between asbestos and human cells, EOS Trans. AGU, 89(53): B53B-0479, 2008.

Schwartz, C.W., Wylie, A.G., Davis, A.P., and James, B.R., (2009), Column Expansion Testing of Chromium tailings Subgrade Fills, International Foundation Congress and Equipment Expo, March 15019, Orlando, FL, 8 pages.

Invited

Wylie, A.G. (2010) Mineralogical Characteristics of Asbestos. GSA meeting, Northeastern/Southeastern sections, Baltimore.

Taylor E, Mossman BT, Wylie AG, Lower SK. (2010) Molecular Methods for the induction of Mesothelioma by Asbestos. GSA meeting Northeastern/Southeastern sections. Baltimore.

Taylor, ES, Lower SK, Mossman, BT and Wylie, AG, 2011. Molecular methods for the Induction of mesothelioma by Asbestos. Biophysics Journal 100. P160a.

Invited

Wylie, A. G. (2013) A Review: Mineralogy and dimensional characteristics of amphiboles from the vermiculite deposit, Rainy Creek Complex, Libby, Montana. GSA meeting Northeastern Section, Bretton Woods, New Hampshire

Invited

Mossman, B.T., Sonali, H, Taylor, E, Lower, S, Dragon, J, bond, J, Wylie, A, and Shukla, A (2013) New Data on How Asbestos Fibers Interact with Cells to Trigger Extracellular Signal-Regulated Protein Kinase, i.e., ERK, Pathways Critical to Toxicity and Disease, 10th International Meeting on fibre/Particle Toxicology, June 407, Dusseldorf, Germany

Segrave, A, Wylie A, and Korchevskiy (2019) Amphibole dimensions and predictive model for potency. ASTM Beard Conference. Denver April 4

Invited

Wylie, A (2019) What makes an amphibole asbestos? History and status of regulatory issues dealing with asbestos. Mineralogical Society of America 100th Anniversary Symposium. Washington DC, June 2019,
http://www.minsocam.org/MSA/Centennial/MSA_Centennial_Symposium.html#S1

Invited

Wylie, A (2019) A metrological look at natural occurrences of amphibole. Association of Economic and Environmental Geologists annual meeting. Asheville NC Sept 19

Invited

Wylie, A and Korchevskiy A (2020) Fibers vs mineral Fragments: Mineralogical and Toxicological aspects. Asbestos 2020 Conference, British Occupational Health Society London Nov 18 2020

Wylie, A (2022) Dimensional parameters and cancer determination of relevant variables. The Monticello Conference, Charlottesville VA April 2022.

Korchevskiy, A and Wylie A (2024) Asbestos terminology: Mineralogical, toxicological and analytical considerations. ASTM Beard Conference, Philadelphia PA April 2024.

f. Guides for Field Trips:

Wylie, A. and P. Candela (1987) "The Geology of the Maryland Piedmont". 3-day Trip and Guide Book. Department of Geology Annual Trip, October 1987.

Candela, P. and A. Wylie (1988) "The Ultramafite-associated Cu-Fe-Co-Ni-Zn Deposits of the Sykesville District, Maryland Piedmont". Goldschmidt Conference Field Trip, May, 1988.

Candela, P. and Wylie, A. (1989) "Fe-Cu-Co-Ni-Zn deposits of Sykesville, Md." International Geological Congress, T241 July 1989. John Wiley and sons

Candela, P. and A. Wylie (1990) "The Ultramafite-associated Cu-Fe-Co-Ni-Zn Deposits of the Sykesville District, Maryland Piedmont". Goldschmidt Conference Field Trip, May, 1990.

Wylie, AG. (2018) Geology of the Catoctin Mountains, MD. June 9, 2018. Geological Society of Washington Spring Field Trip.

Wylie, AG (2022) Geology of the Catoctin Mountains, MD, Nov 6, 2022, Department of Geology University of Maryland College Park

g. Research Grants

Asbestos", U.S. Bureau of Mines, \$84,200. April 1979-April 1981.

Principal Investigator, "Dispersion Staining in Optical Mineralogy", Undergraduate Fund for Improvement of Instruction, University of Maryland, \$700. 1982.

Principal Investigator, "Quality Control in the Analysis of Asbestos by PLM", \$10,000. Sept. 1985-Sept. 1986. Occupational Medical Center.

Principal Investigator "Mineralogy of the Sand Fraction of Aquifer in Northwestern Washington". United States Geological Survey, \$2,450. June-October 1986.

Univ. of Maryland General Research Board Semester Research Award, \$1,500. 1987.

Mineralogy of Waste Product of Sand and Gravel Processing". Aggregate Industries, \$12,000. 1987-1988.

Characterization and Quantification of Fibrous Tremolite in Tremolitic Talc. Southern Talc Company, \$17,000. 1989-1990.

Principal Investigator, "Mineralogical Characteristics of Fibrous Talc". R.T. Vanderbilt Company, \$23,500. September 1992-December 1997.

Project Director, "Fellowship for the Study of Industrial Talc". R.T. Vanderbilt Company, \$33,500. January 1, 1993-December 31, 1997.

Co-Project Director, (with C Schwartz) "Research and Laboratory Testing of Chromium Processing Waste at Dundalk Marine Terminal", Maryland Department of Transportation, \$100,000. December 1996-December 1997.

Co-Project Director (with K Prestegaard and A Amde) "Characterization of Coal Combustion Products and Derived Grout Materials," Nuclear Power Plant Research Program, Maryland Department of the Environment, \$10,000, 1998.

Co-Project Director (with K Prestegaard and A Amde) "Characterization of Coal Combustion Products and Derived Grout Materials, Nuclear Power Plant Research Program, Maryland Department of the Environment, \$60,000, 1999

Co-Project Director, (with K Prestegaard and A Amde)"Characterization of Coal-Combustion Products and Derived Grout Material". Power Plant Research Program, Maryland Department of Natural Resources, \$40,000, 2000.

Co-Project Director, (with K Prestegaard and A Amde)“Characterization of Coal-Combustion products and Derived Grout Material (supplement)□□□ Power Plant Research Program, Maryland Department of Natural Resources, \$60,000, 2000.

Co-Project Director, (with K Prestegaard and A Amde) “A study of the Mineralogical Transformations in Fly-Ash Based Grouts. Maryland Department of Natural Resources, Power Plant Research Program, \$30,000, 2000-2001

Co-Project Director (with P Candela) “A study of the thermal transformation of chrysotile”, Ford, GM and Chrysler, \$610,000, 2004-2006

h. Fellowship, Prizes and Awards

Seven College Conference of Women's Colleges Scholarship to Wellesley College, 1962-1966.

Wellesley College Scholar, 1966.
Wellesley College B.A., *cum laude*

Faculty Fellowship, Columbia University, 1969-70, 1971-72.

Citation from Governor, State of Maryland, for recognition of assistance in implementation of Title IX in Maryland, 1983.

Butler Prize, Geological Society of Washington, 1989. Given for the best paper read before the Society, 1989.

Distinguished Scholar-Teacher 1994 UMCP.

Fellow Geological Society of America 1990

Honorary Membership in Zeta Nu chapter of Eta Sigma Phi 2011

Outstanding Woman of the Year, President’s Commission on Women’s Issues, 2012

President’s Medal, University of Maryland, 2014

Induction in Phi Kappa Phi 2021

3. Teaching, Mentoring, and Advising

a. Courses taught

Course

Approximate Average Enrollment

Physical Geology	150
Economic Geology	10
Optical Mineralogy	6-10

Ore Microscopy	3
Senior Thesis Research	10
Advanced Topics in Economic Geology	14
Geology of Maryland	6
Geology and Public Policy	15
Environmental Geology	60
X-ray diffraction	8

b. Advising: Research Direction

i. Undergraduate Thesis (beginning 1980) Major Advisor:

- 1980** ¹⁶Ed. Jacobsen "Coal Geology of Garrett County, Maryland"
- 1982** Sharron O'Donnell "Coal Geology of Southwestern Kentucky
Eric Windsor "Shape Characterization of Amphiboles"
Morris Levin "Characterization of Part of the Sykesville Magnetite District by a
Magnetometer"
Lyle Griffith "The Use of a Magnetometer in Characterizing the Beasman
Prospect, Sykesville, MD."
¹⁷John Varndell "Heavy Element and Particle Size Relationships in a Sludge
Disposal Site, Baltimore, Maryland"
Joe Segretti "Relationship between cytotoxicity and coating of chrysotile fibers"
Mark Beal, A Geologic Evaluation of a Placer Gold Deposit in Southern
Fauquier Co., Virginia
- 1983** Keith Mason "A Preliminary Evaluation of Copper and Cobalt in Conjunction
with Iron Mining in the Beasman Prospect of Sykesville, Md."
Michael D. Jones "Chromium in the Soils and Streambeds above the Hunting
Hill Serpentine Body, Montgomery County, Md."
Theresa Baker "Crack Growth in Quartz: The Effects of Chemical
Environments"
Mark Hevey "Gas Production and Faulting in Gas Field, Kansas"
- 1984** Brian Hart "A Potential Field Study of the Magnetite Bearing Deposits of the
Central Portion of the Sykesville Mining District"
Katherine Heller "A Reconnaissance Study of the Origin of Small Talc and
Serpentine Bodies in the Wissahickon Formation within the Maryland
Piedmont"
- 1987** Dan Linder "Comparison of the James Run with the Sykesville and Morgan Run
Formation"
Bethany Baker "Observation on the Geology of Montgomery County from
geomagnetic, aeroradioactivity and gravity surveys"
Valerie Gray "Reconnaissance Study on the Source of Gamma Radiation"

¹⁶Winner of the AAPG National Undergraduate Research Award

¹⁷2nd Place Winner of the AAPG National Undergraduate Research Award

Fluctuation in Eastern Montgomery County"

- 1988** Tom Davis "Comparative Geothermometry by Using Garnet-Biotite and Fe-Ti Oxides in the Loch Raven Schist
- 1991** Dan Galasso "Geochemical Prospecting of Heavy Minerals to Determine if a Marker Exists for the Sykesville District of Carroll County, MD"
- 1994** David Berry "Analysis of Trace Quantities of Amphibole Asbestos Based on the Fractal Model for Mass Distribution"
- 1995** Bob Schultz "Determination of Asbestos in a Matrix Through Employment of the Fractal Model for Mass Distribution"
Allan Jackson-Gewirtz "A Comparison of Methods of Analysis of Powdered Samples"
Roberta Winters "Biological Effect of Fiber Size and Mineralogy: The Case of Talc Fibers in Hamster Tracheal Epithelial (HTE) and Rat Macrophage Cells (RMC)"
Mi Lim "Anomalous Optical Properties of Tremolite-Actinolite Fibers"
- 1996** Tom Biolsi "Effects of absorption and thickness in measuring the index of refraction of blue glass and riebeckite and its application to crocidolite"
Katherine White "X-ray diffraction and optical analysis of picrolite from the State Line Quarry, PA"
Christine Rosenfeld, "Characterization of the Chemistry of the Zeolites Erionite and Mordenite as a Function of Morphology: An SEM/EDS study"
- 1997** Matt McMillan "Lattice dimensions vs. chemical composition and optical properties of tremolite"
- 1999** Russell Meyer "Lattice Dimensions, chemical composition and optical properties of crocidolite"

ii. Master of Science Degree Awarded

- 1985** John Ossi, M.S., "A New Petrographic Method for Interpreting Coal-Forming Environments of Deposition"
- 1988** Robert Virta, M.S., "An Evaluation of the Adequacy of Morphological Data for Determining the Carcinogenicity of Minerals"
- 1990** Dan Linder, M.S., "The Mineralogy and Origin of the State Line Talc Deposit, Lancaster Co., Pennsylvania"
- 1991** Tim Rose, M.S., "Petrology and Chemical Variation of Peraluminous Granitic Rocks from the Northern Lobe of the Phillips Pluton, Maine"
- 1996** Jiang Feng, M.S., "Evidence for compositional variation in phyllite from Carroll

and Frederick Counties, MD"

1988 William Greenwood, M.S. "Mineralogical Characteristics of Fibrous Talc"

Diane Hanley, M.S., "Overland flow evaluation of lava flow platform"

1999 Mark Watson, M.S., "Effects of intergrowths on the Physical Characteristics of fibrous Anthophyllite"

2001 Amina DeHarde, M.S., "Characterization of Grouts made from Coal Combustion By-Products: Mineralogy and Physical Properties"

2005 Courtney Crummett, M.S. (co-chair) "Examination of the Thermal decomposition of Chrysotile"

iii. Ph.D.

1991 James Crowley, Ph.D., "Geochemical Study of Playa Efflorescent Salt Crusts and Associated Brines by Using Spectral Reflectance, X-ray Diffraction and Brine Chemical Data"

1999 Martitia Tuttle, Ph.D., "Late Holocene Earthquakes and their Implications for Earthquake Potential of the New Madrid Seismic Zone, Central United States"

4. SERVICE**a. Professional*****i. Offices and Committee Membership Held in Professional Organizations***

Geological Society of America (Fellow)
 Mineralogical Association of Canada
 Geological Society of Washington
 American Association for the Advancement of Science
 American Geophysical Union
 Geological Society of America Campus representative (1985-2000)
 Chairman, Sigma Xi Graduate Student Research Award Selection Committee, UMCP
 (1986, 1987)
 Mineralogical Society of America: Tellers committee, 1989-1991.
 Representative to American Geological Institute, K-12 Education Committee, 1991
 Field Trip Chairman, Geological Society of Washington, 1990.
 Delegate to AAPG - Geological Society of Washington 1995-96.
 International Mineralogical Association Chair, Committee on Asbestos nomenclature
 2019-2022

ii. Reviewing Activities for Journals and Agencies

<i>American Mineralogist</i>	Environmental Protection Agency
<i>Canadian Mineralogist</i>	U.S. Geological Survey
<i>Science</i>	<i>Economic Geology</i>
<i>Environmental Research</i>	Society of Mining Engineers
U.S. Bureau of Mines	<i>American Industrial Hygiene Journal</i>
<i>European Journal of Mineralogy</i>	<i>Critical Reviews in Toxicology</i>
<i>Periodico di Mineralogia</i>	<i>Scientific Reports</i>
National Institute for Occupational Safety and Health	
<i>Risk Analysis</i>	

iii. Other Professional Activities

Co-Chairman, New York Academy of Sciences, Workshop #1. Significance of Aspect Ratio in Regulation of Asbestos Fiber Exposure, Conference on the Scientific Basis for the Public Control of Environmental Health Hazards, New York (1978).
 Invited Chairman and Organizer of "Asbestiform Minerals Symposium", AIME Annual Meeting (1979) Tucson, Arizona.
 Appointed by the U.S. Secretary of Education to the Task Force on Asbestos in the Schools (1980-1984).
 Session Chairman, EPA Conference on Monitoring and Evaluation of Airborne Asbestos Levels Following Abatement, March, 1984.
 Appointed reference analyst for U.S. Navy Asbestos Analysis Quality Assurance Program (administered by Research Triangle Institute) 1984-1990.
 Session Chairman, Economic Geology III, Geol. Soc. of Amer. National Meeting, November 1985.

Member, ASTM Task Group for writing Standard Methods of Analyses of Asbestos by TEM, SEM, Phase Contrast Optical Microscopy and Polarized Light Microscopy. 1985-1990. Author of Polarized Light Microscopy Method (grey sheets).
Expert witness, Occupational Safety and Health Administration hearing on asbestos regulation, 1985, 1990.
Invited participant, Penn. Geol. Survey Conference on Mapping in the Piedmont, 1987.
Expert panel member, EPA, Superfund Bulk Asbestos Method, 1990-1991.
Member IARC Work Group for Talc, Carbon Black, and Titanium Dioxide, Lyon France 2006.
Wellesley College, Class of 1966 Class Officer 1981-86, 2006-11; Annual giving committee 2012-2016
Member, Peer Review Panel, NIOSH, Roadmap for Scientific Research on Asbestos and Other Mineral Fibers, 2007
Testimony, US House Senate, Committee on Environment and Public Work June 12, 2007 and follow-up letter, June 16, 2007
Member, Scientific Advisory Board, National Stone, Sand and Gravel Association 2011-present
Member, Frederick Regional Higher Education Advisory Board 2013-2015
Member, Frederick Center for Research and Education in Science and Technology (CREST) Governing Board 2015-2018
Member Planning Committee for NIOSH EMP workshop on Terminology and Characterization, Paul Middendorf Chair 2016 (rescheduled by CDC to 2017).
Invited participant and member of the Planning Committee, National Academies Workshop on elongated Mineral Particles, May 15-16 2017. (Rescheduled to January 2018: cancelled by NIOSH in January)
Co-chair NSSGS/Society of Toxicology Monticello Conference on EMPS, October 2017, Charlottesville, VA
Guest editor. Special issue of Toxicology and Applied Pharmacology: The Monticello Conference.
Invited speaker and session co-moderator, JIFSAN workshop. Asbestos in talc. Nov 2018
Steering committee and session co-chair: Dimensions and Mesothelioma. The Monticello Conference II on Elongated Mineral Particles and Cancer. April 2022, Charlottesville VA

c. Selected University of Maryland Service

Chairman, Institutional Review Board (IRB) 1984-1986
Supervisory responsibility for Animal Care and Use Committee and actions (1984-1986)
Chair, General Research Board 1984-1986
Chair, Creative and Performing Arts Board 1984-1986
Member Review Committee for Dean of the College of Computer Mathematical and Physical Sciences 1990
Member, Review Committee for Chair of Department of Economics 1998
Chair, Earth System Science Director Search Committee 1998
Chair, Limited Enrollment Committee, 2000-2002
Chair, Campus Assessment Working Group, 2000-2002
Chair, Search Committee, Vice President for Research 2002
Chair, Search Committee, Vice President for Administration and Finance, 2004
Chair, UMCP Graduate Council, 2004-2006
UMCP Strategic Planning Steering Committee, Graduate Education Chair, 2008

Chair, UMCP Finance Committee, 2008-2011
Chair, UMCP Sustainability Council 2009-2011
Chair, Student Fee Review Committee 2008-2011
Chair, UMCP Facilities Council, 2011-2012
MPowering the State, UMB-UMCP Steering committee 2011-2013
Carey School of Law Dean Search committee 2013-2014
Facilitator, Leadership Fellows Program, UMCP Advance. 2013-2014
College of Computer, Mathematical and Natural Sciences, University of Maryland,
Board of Visitors, 2013-2018
Member. UM Investigation Committee for scholarly misconduct case. 2015
Chair, Investigation Committee to review UM Maryland Industrial Partnership grant to
Fifth Quarter Fresh and School of Public Health. 2016
Chair, Transition Committee, President Designate Professor Darryll Pines, University of
Maryland, 2020
Chair, Task Force on Geoscience, College of Computer, Math and Natural Sciences,
2020
Chair, Climate Working Group, University of Maryland, 2023

Appendix 5 – List of MAS Reports Identifying “Chrysotile” in Johnson & Johnson Talcum Powder Products

Date	MAS Project Number(s)
2/24/2020	M70484
3/6/2020	M66515 & M66516
3/18/2020	M71095
3/20/2020	M70877
4/6/2020	M71046
5/14/2020	M71095 Rev 1
9/16/2020	M71109-M71111
9/17/2020	M71166
9/23/2020	M71095 Rev 2
9/29/2020	M71166 Sup 1
12/8/2020	M71166 Sup 2
1/25/2021	M71211
2/9/2021	M71241
3/23/2021	M65329-013; M66507-001; M66508-001; M66509-001; M66513-001; M67420-001; M67420-002; M67420-004; M67420-005
4/13/2021	M71216
5/25/2021	M71228
6/4/2021	M70859
8/20/2021	M70877
3/11/2022	M71262
2/28/2023	M71614
10/19/2023	M71643
11/28/2023	M71730
2/15/2024	M71740

Appendix 6 – Reference List

In addition to the documents listed on my *curriculum vitae*, which is attached as Appendix 4, I have also cited to the below references as part of this report:

Bloss, F. Donald, An introduction to the Methods of Optical Crystallography. Holt, Rinehart and Winston, New York, 1960.

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Shu-Chun, Su., A rapid and accurate procedure for the determination of refractive indices of regulated asbestos minerals, American Mineralogist 88:179-182, 2003.